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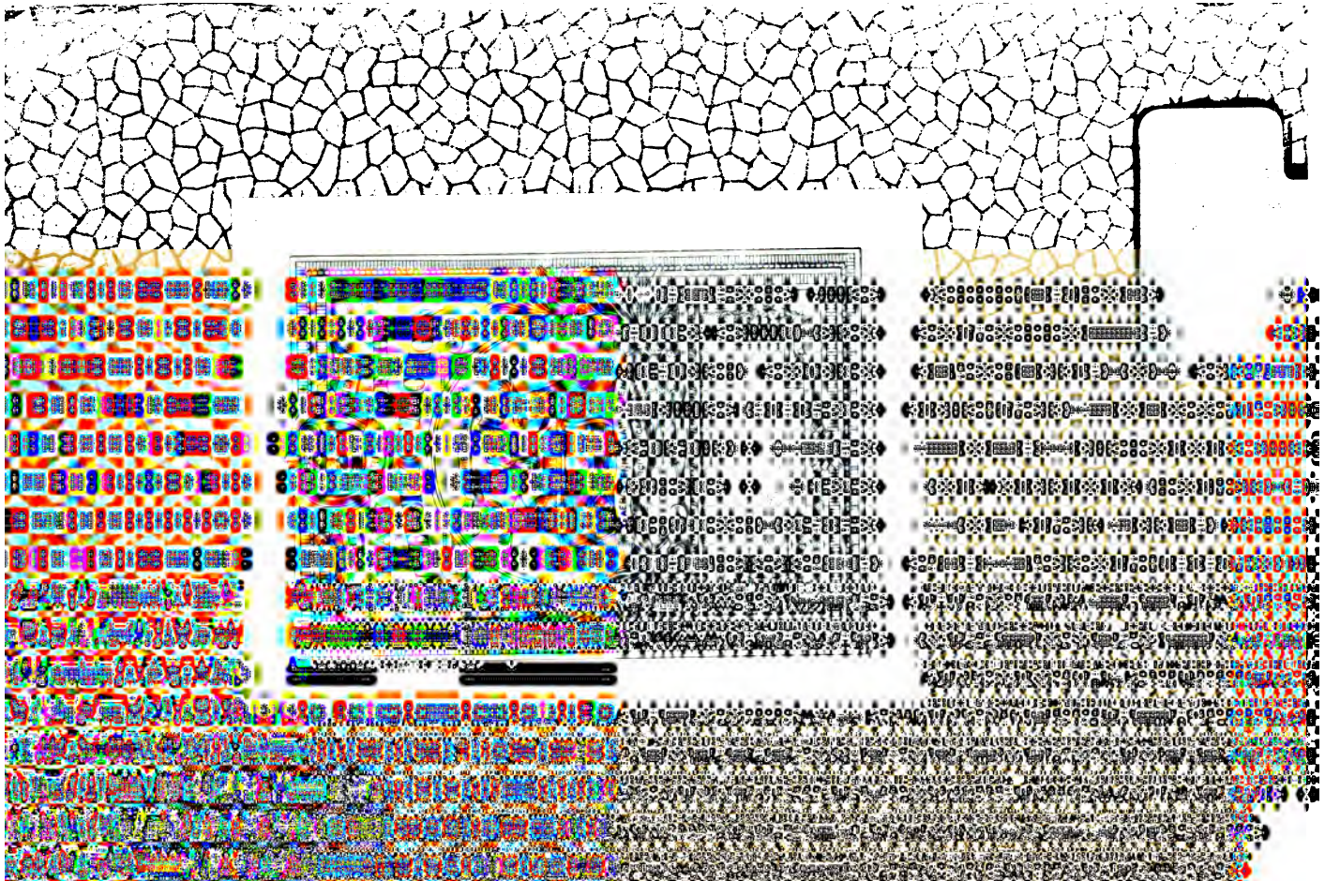

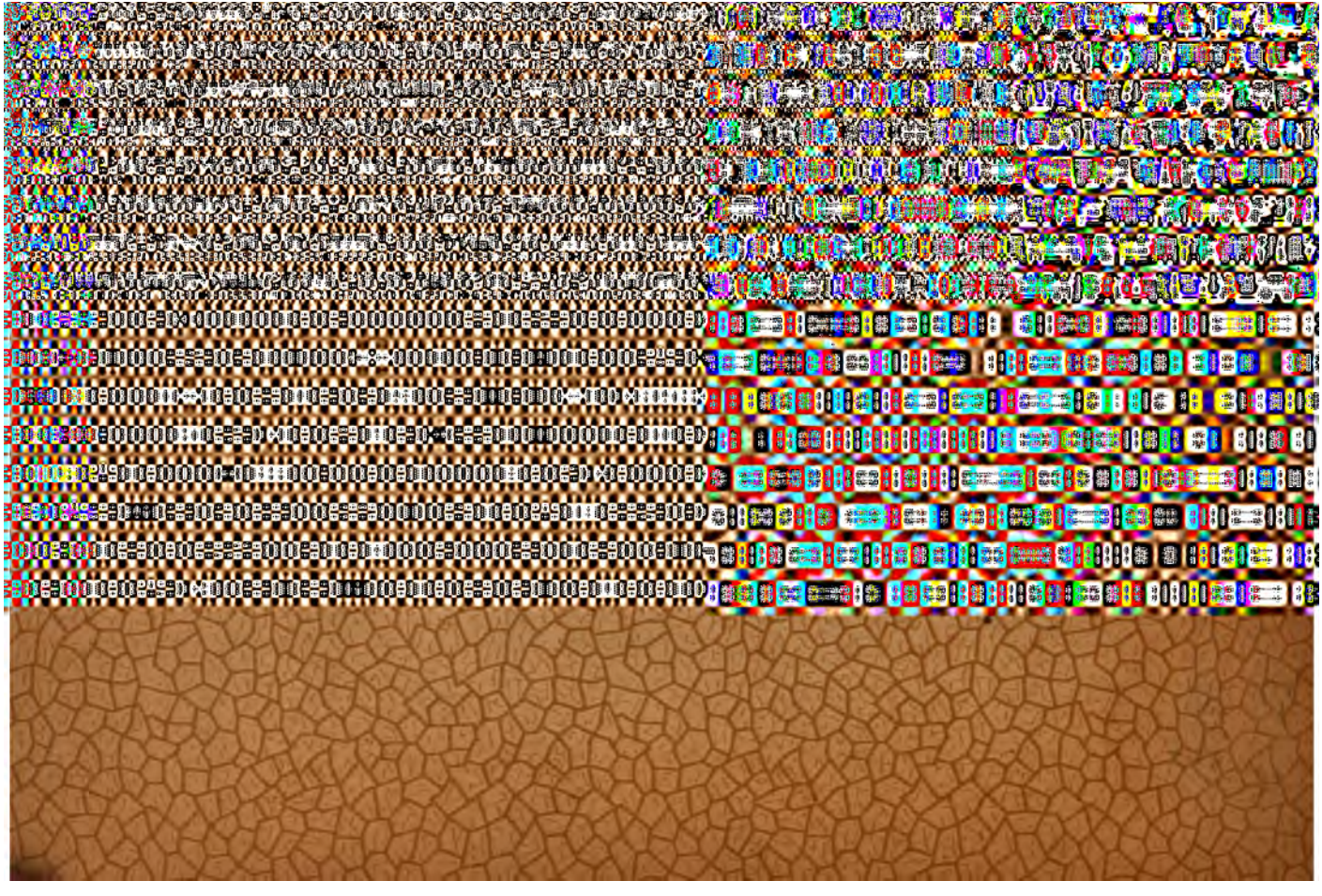

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# PRACTICAL WORK IN PHYSICS

## PART II. HEAT

*WOOLLCOMBE*

HENRY FROWDE, M.A.

PUBLISHER TO THE UNIVERSITY OF OXFORD

LONDON, EDINBURGH, AND NEW YORK

# *Practical Work in Physics*

*FOR USE IN SCHOOLS AND COLLEGES*

BY

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PART II. HEAT

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'The primordial causes are not known to us: but they are subject to simple and constant laws, which one can discover by observation, and the study of which is the object of natural philosophy.'—FOURIER.

# PREFACE

AN essential feature in the four parts of *Practical Physics for Schools and Colleges*, of which this is the second, is to offer a fairly complete experimental course in the ground covered at but a trifling cost. The apparatus required is inexpensive, and may be readily obtained or easily made from the ordinary stock of a Chemical Laboratory. In addition to what is stated in the Introduction to the first part, it may be remarked that a course of Practical Work in Heat is perhaps one of the best means of training the powers of accurate observation and reasoning. This subject is more subtle in its nature than other branches of Physics, and a student has to be continually on the alert to bring an experiment to a successful conclusion. The author begs to thank Mr. H. G. Madan, M.A., of Queen's College, Oxford, and Professor Poynting, F.R.S., of The Mason Science College, Birmingham, for several important suggestions which have been incorporated in the work, and Mr. T. J. Baker, B.Sc., who has kindly revised the manuscript for the Second Edition.

KING EDWARD'S HIGH SCHOOL, BIRMINGHAM:
*July*, 1896.

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*Those experiments which are marked with an asterisk (*) are suitable only for older students.*

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In addition to the apparatus and material, usually at hand in a Chemical Laboratory, the following will be required :—

Two thermometers, reading to 200° and 300° C.
Cylindrical iron vessel for Expt. 8.
Hypsometer for Expt. 9.
Tubes of Brass, Iron, and Copper about 120 cm. in length.
Microscope with a divided scale in the eyepiece (Quincke's pattern).
Density Bottle with perforated stopper.
Dulong and Petit's expansion apparatus for Expt. 16.
Three bulb-tubes with long graduated stems.
Increase of air-pressure apparatus for Expt. 26.
A metal vessel to be used as a Calorimeter.
Vapour pressure apparatus for Expt. 42.
Regnault's Hygrometer.
Wet and Dry Bulb Thermometers.

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*The apparatus required for this volume may be obtained from* MR. W. GROVES, 89, *Bolsover Street, Portland Place, W., who will forward a price list on demand.*

# PRACTICAL WORK IN HEAT

## A. THERMOMETRY.

**1. Corrections to be applied to the reading of a barometer.**

The standard barometer is graduated when both the scale and the mercury are at 0°C, so that we ought always to reduce our reading, $h$, of the barometer at the temperature, $t$, of the room to what it would be if the scale and the mercury were at 0°C.

($a$) Each unit length of the scale at $t°$ is longer than it would be at 0° by $1+bt$, where $b$ is the coefficient of linear expansion of the metal scale[1]. Our reading $h$ is therefore too low, and the height corrected for the expansion of the scale is $h(1+bt)$.

($b$) Since the density of mercury at 0°C is $1+\delta t$ times greater than its density at $t°$, where $\delta$ is the mean coefficient of absolute expansion of mercury between 0° and $t°$, the column of mercury at 0° representing the atmospheric pressure would be $1+\delta t$ times shorter than the column at $t°$. Our reading therefore is too high, and the height $h(1+bt)$ corrected for the expansion of the mercury is

$$\frac{h(1+bt)}{1+\delta t} = h(1+bt)(1+\delta t)^{-1} = h(1-[\delta-b]t), \text{ nearly.}$$

If the scale is of brass $b=\cdot 000019$, and taking the coefficient of expansion of mercury $\delta$ to be $\cdot 00018$, this expression becomes

$$h(1-\cdot 00016t).$$

($c$) There are two other corrections to be made: one for the index error, which is merely the mistake of the maker; the other

[1] Or of glass if the scale is etched on the glass tube itself.

for capillarity, which depends on the diameter of the tube. These two corrections are made once for all for a given barometer and must be added to all reduced observations.

N.B. For comparison of barometric readings at different places on the earth's surface the readings have also to be reduced to the sea-level at the equator, since the weight of the column of mercury varies with the height above the earth and with the latitude.

*Example.* On a day, when the temperature was 15°, the height of the barometer was $754{\cdot}3^{mm}$. Reduce this reading to 0°.

The reduced height is $754{\cdot}3\,[1-{\cdot}00016\times 15]=752{\cdot}49$

Capillarity and index error= ·24

Corrected height=752·73

**2. Correction to be applied to the reading of a thermometer.**

When the whole of the thread of mercury in a thermometer is not immersed in the substance whose temperature we are measuring, the thermometer reading is somewhat too low, and we must apply a correction to it to give us the true temperature of the substance.

Suppose $T°$ the true temperature of the substance,

$t°$ the temperature indicated by the thermometer,

$t'°$ the mean temperature of the air near the thermometer,

$n$ the number of thermometer divisions occupied by the thread of mercury outside the substance,

$\Delta$ the excess of the coefficient of expansion of mercury over that of glass.

If both glass and mercury expanded equally the increase of temperature of the stem from $t'°$ to $T°$ would not alter the reading, but, since mercury expands more than glass, an additional fraction, $\Delta(T-t')$, of the original volume of the mercury would be occupied by it along the stem. The original volume is indicated by the $n$ divisions, occupied by the mercury outside the substance, and therefore the additional length of the stem that would be occupied, if the whole thread were immersed

in the substance, is $n\Delta(T-t')$ divisions, if we disregard the slight change in volume of this part of the stem due to the increase of temperature. Therefore the true temperature of the substance is given by

$$T = t + n\Delta(T-t'),$$

where $\Delta = \cdot 000155$.

*Example.* Find the true temperature of water when a thermometer, immersed up to the 20th degree, shows a temperature of 80·3°, while the temperature of the surrounding air is 16·7°.

$$T = 80\cdot3 + 60\cdot3 \times \cdot000155\,(80\cdot3 - 16\cdot7)$$
$$= 80\cdot89°.$$

**3. To compare two thermometers.**

It is often convenient and sometimes necessary to use two thermometers in an experiment, and, as mercury thermometers seldom exactly agree, it is important to compare one with the other.

*Apparatus.* Two thermometers: Beaker: Sand-bath: Retort-stand and Clamp: Bunsen Burner: Curve-paper[2].

*Experiment.* Tie the two thermometers together and support them by the clamp so that they dip vertically into a beaker of water placed on a sand-bath. Heat the water gradually, keeping the whole of it well stirred[3] continually. About every five degrees rise of temperature take the readings of each thermometer[4]. Enter the corresponding temperatures in two adjacent columns. Continue taking readings until the water boils.

Plot a curve of your results as follows:—Take a piece of curve paper and draw two straight lines at right angles to each other near the lower and the left-hand edges of the paper. These lines are called the axes of the curve, and the point of their intersection the origin. Along the bottom line [the line of abscissae] mark off equal spaces to represent 5°.

[2] See Appendix B. 8.

[3] Stirring is a most important operation where uniformity of temperature is required. A feather or a flat piece of wood does well for a stirrer, though it is better to use some means of stirring vertically.

[4] In reading a thermometer place your eye on a level with the top of the mercury thread, and always estimate to tenths of a division. A pocket magnifying glass is useful for the purpose.

The number of divisions on the paper to be taken to represent 5° must depend (*a*) on the number at your disposal and (*b*) on the range of temperature to be indicated. Along the left-hand vertical line [the line of ordinates] mark off equal spaces [not necessarily of the same length as before] to represent 5°. Along the horizontal line place very small dots at the points representing the temperatures you have read on thermometer *A*, and along the vertical line at the points representing the temperatures read on the thermometer *B*. Now mark with a very small cross the points obtained by the intersection of *imaginary* vertical lines through the temperatures of *A* with *imaginary* horizontal lines through the corresponding temperatures of *B*. Draw carefully a fine continuous line [curved or straight as the case may be] which will pass through the average run of the series of points so obtained[5]. The points along this curve represent also those which we have not determined by experiment. We can now easily find what temperature on one thermometer corresponds to a given temperature on the other. For, if we wish to know what temperature on *B* corresponds to 55·5° on *A*, draw a vertical line through the point representing this temperature on *A*, and from the point where this line intersects the curve draw a horizontal line. This will cut the vertical temperature line of *B* at the required point. Fig. 1 shows a curve obtained by comparing two given thermometers.

**4. To test the freezing-point of a thermometer.**

*Apparatus.* Funnel: Beaker: Thermometer: Retort-stand: Ice.

*Experiment.* Place the funnel in a ring of the retort-stand and under it place the beaker. Hang the thermometer with its bulb inside the funnel so that the zero is on a level with the

[5] The curve will not pass through all the points unless your observations have been perfectly exact. Some points will probably be above and some below the final curve. It is a good thing to use a piece of thin cardboard or a flexible lath as a guide when tracing the curve. When a curve is completed, always write along the top edge of the paper the experiment to which the curve refers, and along the horizontal and vertical axes the name of the measurements to which their corresponding divisions refer.

90°
100°

rim. Well wash a piece of ice and with a chisel scrape off some shavings. Pack these round the thermometer in the funnel. Pour over them some distilled water and determine the lowest point to which the mercury sinks. The difference between this point and 0° will be the zero error of the thermometer.

N. B. Except in cases in which a difference of temperatures, each of which is measured by the same thermometer, is required, the zero error of the thermometer must be known and a suitable correction applied to the reading taken with it.

**5. To test the boiling-point of a thermometer.**

*Apparatus.* Flask fitted with a two-holed bung: Short elbow-tube: Thermometer: Sandbath: Bunsen Burner.

*Experiment.* Fill half the flask with water. Fit the elbow-tube into one hole, the thermometer into the other hole of the bung. Arrange the thermometer so that, on placing the bung in the flask, the bulb is about 1 cm. above the surface of the water. Place the flask on the sandbath and apply heat. When the water has boiled briskly for some time, and the thermometer has risen as far as it will, read the temperature. This gives the boiling-point under the present atmospheric pressure as indicated by this thermometer. To find whether the thermometer reads correctly we must calculate what temperature would be indicated by it when water boils under a pressure of $760^{mm}$, the true boiling-point under this pressure being 100°. From the tables [Appendix A. 10], giving the boiling-points of water under different pressures, we find that an increase of $26{\cdot}8^{mm}$ in the pressure causes a rise of 1° in the boiling-point. Hence, if $H$ is the present atmospheric pressure, and $x°$ the required correction to be added to the temperature, read above, to get what the thermometer would indicate as the boiling-point of water under a pressure of $760^{mm}$,

$$x° : 1° :: 760 - H : 26{\cdot}8.$$

The difference between the corrected temperature and 100° is the error of the boiling-point.

*Example.* A thermometer marks 99·3° as the boiling-point

of water when the height of the barometer is $755{\cdot}5^{mm}$. Find the error of the thermometer.

$26{\cdot}8 : 4{\cdot}5 :: 1^\circ : x^\circ$; $\therefore \quad x = {\cdot}17^\circ$, nearly.

| | | |
|---|---|---|
| Thermometer reading | = | 99·3 |
| Correction | = | ·17 |
| | | 99·47 |
| Error of boiling-point | = | ·53 |
| | | 100·00 |

**6. Determination of the melting-point of a solid** (Method **1**: Directly).

*Apparatus.* Glass tube drawn out to a fine bore: Beaker: Test-tube: Thermometer: Sandbath: Bunsen Burner: Paraffin-wax.

*Experiment.* Melt the wax in the test-tube and draw up some of the liquid into the narrow glass tube. Fuse the end and tie it to the thermometer and support vertically in a beaker of water placed on the sandbath. Heat the water, keeping it continually stirred. Note the temperature at which the wax begins to be transparent at one particular point of the tube. Remove the beaker from the sand-bath, and allow the water to cool, keeping it stirred. Note the temperature at which the wax begins to solidify at the same point as before. The mean of the two readings will give the melting-point approximately. Lower the flame and heat very gently, so as to determine the melting-point as above more accurately. Repeat this twice more and take the mean of the results as the true melting-point.

Determine as above the melting-points of Beeswax and Stearic Acid.

**7. Determination of the melting-point of a solid** (Method **2**: By a time-curve).

*Apparatus.* Test-tube fitted with a two-holed cork: Beaker: Thermometer: Sandbath: Retort-stand: Watch: Bunsen Burner: Paraffin-wax: Curve-paper.

*Experiment.* Fill the test-tube with the melted wax and fix

the thermometer[6] in the cork so that it dips into the melted wax up to the 20th degree or so. Support the test-tube by a string to the retort-stand and bring up a beaker of water to immerse it completely. Heat the water till the wax is all melted. Take away the beaker, wipe the test-tube dry, and allow the wax to cool gradually. Note the temperature indicated by the thermometer every half minute until the wax has become quite solid and has cooled to about 30°. Arrange your results in a tabular form as follows:—

| Times. | Temperatures. |
|---|---|
| ..... | ..... |
| ..... | ..... |

Plot your results in a curve taking the times as abscissae and the corresponding temperatures as ordinates. Since the liquid gives out its heat of fusion on solidifying the temperature will for some time remain more or less stationary at this point. Therefore the curve will show two turning-points or points of inflexion. The line between them is approximately parallel to the axis of times, and, if produced, will cut the axis of temperatures at the required melting-point. Compare your result with that of Experiment 6.

Determine as above the melting-points of Beeswax and Stearic Acid.

### *8. Determination of the melting-point of an alloy.

[*A* is a cylindrical vessel of sheet iron, 3 cm. in diameter, 6 cm. in height. In the middle of it is fixed a metal tube *B*, 1 cm. in diameter. Between *A* and *B* is the alloy. The tube *B* contains mercury, the level of which is just above that of the alloy.]

*Apparatus* (Fig. 2). Thermometer: Watch: large Bunsen Burner: Mercury: Common Solder [equal parts by mass of Lead and Tin]: Curve-paper.

*Experiment.* Fill the outer cavity of the apparatus about three

[6] The thermometer ought previously to be warmed carefully over a flame to prevent its breaking when placed in the melted wax.

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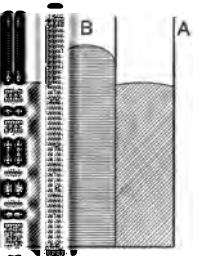


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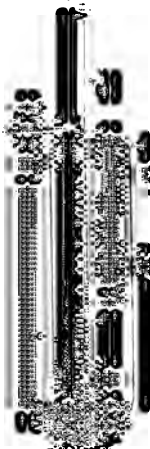

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*Experiment.* Support the apparatus in a beaker of cold water so that the shorter limb is completely immersed, and place a thermometer close to it. *Gradually*[9] heat the water, keeping it continually stirred. The pressure of the vapour of the liquid in the tube will increase and will depress the mercury in the shorter limb. When the level of the mercury is the same in the two limbs the pressure of the vapour is equal to the atmospheric pressure. The temperature at which this is the case is the boiling-point of the liquid, and must be noted. On taking away the burner the mercury in the right-hand limb may continue to rise for a little. If so, allow the water to cool and take another reading of the thermometer when the two columns return to the same level. Repeat this twice more, and take the mean of your readings as the boiling-point of the liquid under the existing atmospheric pressure. Record both the temperature and the barometric height.

Determine as above the boiling-points of Ether and Carbon Bisulphide, and Turpentine (using an oil bath).

***11. To compare the variation of the boiling-point of a saline solution with its strength.**

*Apparatus.* A flask about 400 c.c. capacity fitted with a cork through which pass a short elbow-tube and a thermometer:

a sand-bath. When we begin to heat a beaker of water, moisture condenses on the outside. The air always contains aqueous vapour, and the warmer the air is the greater the quantity it can contain. The layer of air in contact with the outside of the beaker, being cooled by the water, cannot therefore contain as much vapour as the warm air rising from the Bunsen flame. Therefore moisture condenses and soon collects into drops of water, which, if allowed to trickle down to the bottom of the beaker, are apt to crack it. Thus it is necessary to begin to heat the water gradually by moving the flame about. When the temperature of the water has risen to 30° or 40° the moisture disappears and there is no further danger.

[9] It is necessary to insist upon the fact that it is useless to try and 'rush' an experiment. The student must take time over it and be continually on the alert in watching the process. Otherwise the result will be useless or the experiment will completely fail and time will be wasted. In this particular experiment it has been frequently found that a student places a burner under the beaker of water containing the *U*-tube and either neglects to watch the rise of temperature or to stir the water. The result is that the temperature rises above the boiling-point of the liquid enclosed and the mercury is expelled with violence and the tube has to be filled again.

Sand-bath: Bunsen Burner: Crystallised Calcium Chloride: Curve-paper.

*Experiment.* Drop a small piece of clean coke or some pieces of broken glass into the flask to prevent boiling with bumping and counterpoise the flask and cork. Fill the flask about one-third full of distilled water and arrange the thermometer with its bulb under the surface. Note the temperature, $t$, at which the water boils. Weigh the flask and its contents to find the mass, $M$, of the water present. Put about 20 grams[10] of the salt into the flask, and weigh again to find the exact mass, $m_1$, of the salt added. Boil this solution and note the boiling-point $t_1$. Weigh the flask so as to determine the mass, $M_1$, of the solution. Add about 20 grams more of the salt. Weigh again to determine exact mass, $m_2$, added. Boil and note the boiling-point $t_2$. Weigh to determine the mass, $M_2$, of the solution. Repeat this process until the boiling-point rises to about 150°. Read the barometer and enter your results in a tabular form as follows:—

Barometric pressure, ... mm.

| Mass of salt added. | Mass of contents of flask after boiling. | Percentage of solid in solution. | Boiling-point. |
|---|---|---|---|
| 0 | $M$ | 0 | $t$ |
| $m_1$ | $M_1$ | $\pi_1$ | $t_1$ |
| $m_2$ | $M_2$ | $\pi_2$ | $t_2$ |
| $m_3$ | $M_3$ | $\pi_3$ | $t_3$ |
| ... | ... | ... | ... |

The composition of crystallised Calcium Chloride is

$$\begin{array}{l} Ca\,Cl_2 + 6\,H_2O \\ 111 \quad + 108 \quad = 219, \end{array}$$

therefore the mass of solid present is $\frac{111}{219}$ths of the mass of the salt added. To get the numbers in the third column let us find $\pi_3$. The mass of salt added is $m_1 + m_2 + m_3$, therefore the

[10] In the case of anhydrous salts add about 10 grams each time. No correction for the water of crystallisation will be necessary in this case.

mass of solid present is $\frac{111}{219}(m_1+m_2+m_3)$. Thus the percentage of Calcium Chloride in the contents of the flask is

$$\frac{111\,(m_1+m_2+m_3)}{219\times M_3}\times 100.$$

Plot a curve, taking the percentages as abscissae and the corresponding boiling-points as the ordinates, marking the origin of temperatures 100°.

N.B. At certain stages of the experiment, it may be well to concentrate the solution by boiling the water away instead of by adding more salt.

Determine as above the variation of the boiling-point with solutions of Potassium Nitrate and of Sodium Chloride.

## B. Expansions.

The *coefficient of linear expansion* of a solid is that length by which 1 cm. of it expands on being heated from 0° to 1°C.

The *coefficient of cubical expansion* of a substance is that volume by which 1 cub. cm. of it expands on being heated from 0° to 1°C.

The expansion of solids and liquids is in general very nearly constant for successive degrees of temperature, and so small as to allow us, without appreciable error, to determine the coefficient of expansion by finding the mean expansion per linear or cubic cm. for 1°C, between the ordinary limits of temperature in an experiment. The expansion of gases is, however, too large to allow us to do this, and therefore we must either start with the gas at 0°C, as in Experiments 24 and 26, or reduce the results to 0°C as in Experiment 25.

### 12. Determination of the coefficient of linear expansion of a metal tube [11].

[*M* is the metal tube, about 120 cm. in length, firmly fixed at one end by a short piece of metal rod passing through a holdfast *S* fixed in the wall. Near the other end, which rests in a groove made in a fixed support, is soldered the needle *N*. Through the cork, closing this end, passes a piece

[11] I believe this method is due to my predecessor, Mr. A. D. Hall.

of glass tubing, connected by india-rubber tubing with an elbow-tube, passing tightly through the cork of the boiling can *B* [12].]

*Apparatus* (Fig. 5). Microscope with a divided scale in the eyepiece: Thermometer: Bunsen Burner.

*Experiment.* Measure the distance, *L*, between the fixed end and the needle, and note the temperature, *t*, of the room. Arrange the microscope so as to focus an edge of the needle on one of the extreme scale-divisions in the eyepiece, remembering that the direction of the motion of the needle, when the rod expands, is reversed by the microscope. When once adjusted be careful not to move the apparatus during the experiment.

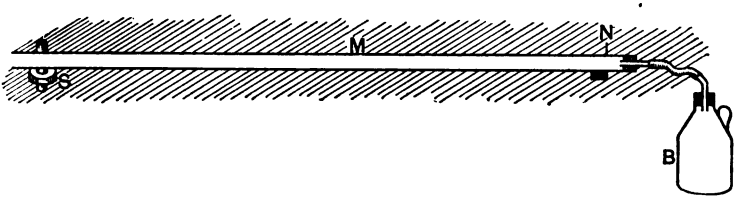



Fig. 5.

Now boil the water in the can and allow the steam to pass through the tube. The tube will expand, and the needle will be seen to move across the scale. Continue to pass the steam until the needle comes quite to rest. Count the number of scale divisions the needle has moved over and multiply by the known value of a scale division [13] in centimetres. This gives us the length, *l*, by which the tube has expanded. Read the barometric height, and find from the tables [Appendix A. 10] the temperature, *T*, of boiling water at this pressure [14]. Then

[12] An ordinary oil can, through the cork of which passes an elbow-tube, is a convenient boiling can. Cans made of copper last much longer than the tin ones, as rust eats holes into the bottom of the latter.

[13] This is easily obtained by looking through the microscope at a metre rule and noting how many millimetres are covered by the scale. The scale in use in the writer's laboratory covers 2 mm. and is divided into 100 divisions.

[14] If the error of the thermometer by which we measure the temperature of the air is not known (Experiment 5), it is better to measure the temperature of boiling water with the same thermometer instead of referring to the tables. Whenever a difference of temperatures is required, as in this case,

$L$ cm. have expanded by $l$ cm. for a rise of temperature $(T-t)°$
$[\tau°$ suppose$]$

$\therefore$ 1 cm. expands by $\frac{l}{L\tau}$ cm. for a rise of 1°C,

which is the required coefficient of linear expansion of the tube.

Determine as above the coefficients of linear expansion of Iron, Copper and Brass.

**13. Determination of the coefficient of cubical expansion of glass by the density bottle.**

*Apparatus.* Density bottle with perforated stopper: Beaker: Thermometer: Sandbath: Bunsen Burner: Mercury.

*Experiment.* Thoroughly clean and dry[15] a density bottle. Counterpoise it[16] and then fill it with Mercury, while the density bottle is immersed up to its neck in water. Read the temperature, $t$, of the water. Take the bottle out and dry it, being careful not to handle it more than is absolutely necessary[17]. Find the mass, $M$, of the mercury it contains at this temperature. Replace the bottle in the beaker[18] and boil the water. After allowing it to boil for a few minutes take the bottle out again, dry it carefully and weigh to determine the mass, $M'$, of mercury remaining in it. Note the temperature, $T$, of the boiling water. The mass of mercury that has been expelled is $M-M'$, or $m$ suppose. Hence the mass, $M'$, of mercury has not only expanded to fill the increased volume of the bottle, but has also occupied the place of the $m$ grs. which have been expelled. We may take these masses as proportional to the

the error is eliminated by measuring both temperatures with the same thermometer.

[15] See Appendix B. 3.

[16] Bullets, shot, and sand are convenient to counterpoise bodies with.

[17] Since the temperature of the room is in general somewhat higher than that of the water, it is best to take out the stopper carefully and to place it by the side of the bottle on the pan of the balance. This prevents any loss of mercury that may ooze through the stopper by reason of its expansion from this cause.

[18] To prevent mishaps we must not place the bottle on the bottom of the beaker but on a low support when boiling the water: e. g. on a clay triangle whose three wire ends are bent downwards to form three legs.

volumes, since both were at the same temperature at the moment of expulsion, hence

$M'$ cub. cm. of mercury expand in excess of the glass by $m$ cub. cm. for $(T-t)°$ [$\tau°$ suppose]

$\therefore$ 1 cub. cm. expands by $\frac{m}{M'\tau}$ cub. cm. for 1°C.

This gives us the mean coefficient of expansion of mercury ($\Delta$) relative to glass between these temperatures. The co-efficient of expansion of glass ($k$) may be taken approximately as the mean absolute coefficient ($\delta$) less the mean relative coefficient of expansion of mercury.

Look in the tables [Appendix A. 2] for the mean absolute co-efficient of expansion of mercury between $T°$ and $t°$, and from it subtract the above value of $\Delta$ in order to get the coefficient of expansion of the glass, and enter your results as follows:—

| | | |
|---|---|---|
| $M$ = ... grs. | | $T$ = ...° |
| $M'$ = ... grs. | | $t$ = ...° |
| $\therefore$ $m$ = ... grs. | Tables give $\delta$ = ... | $\therefore$ $\tau$ = ...° |

$$\Delta = \frac{m}{M'\tau} = \ldots$$

$$\therefore\ k = \ldots$$

N.B. To illustrate the method of calculating $\delta$ from the numbers given in Appendix A. 2, suppose we require the mean absolute coefficient of expansion of mercury between 10° and 50°. From the table we find that 1 c.c. of mercury at 0° becomes

| | |
|---|---|
| | 1·0090 at 50° |
| | 1·0018 at 10° |
| $\therefore$ Total expansion for 40° = | ·0072 |
| $\therefore$ mean absolute coefficient of expansion between 10° and 50° = | ·0018 |

***14. Determination of the coefficient of cubical expansion of glass by the weight thermometer.**

*Apparatus.* A piece of fairly thick glass tubing about 15 cm.

long and 1·5 cm. in diameter: Beaker: Thermometer: Evaporating Dish: Crucible: Retort-stand: Bunsen Burner: Mercury.

*Experiment.* Clean and dry the glass tube. Hold it in the flame of a Bunsen's burner and heat it near one end, keeping on turning it round so as to heat it uniformly. When quite viscous draw it out while still in the flame and so close the end. Anneal it by holding the closed end in an ordinary gas flame until it is covered by a deposit of carbon and allowing it to cool gradually.

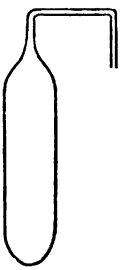


Fig. 6.

When it is cool, heat it uniformly near the other end, and when viscous take it out of the flame and draw it out to a fine tube. Bend it as in the figure, and cut off with a file any superfluous tube. Counterpoise this weight thermometer. Then support it by a wire so that its beak dips under the surface of clean dry mercury [Appendix B. 4] in an evaporating dish resting on a ring of the retort stand. We have now to fill the thermometer with mercury. This we do by heating it so as to drive out some air, and then allowing it to cool again[19], when the atmospheric pressure will force some mercury in. When, by alternately heating and cooling, we have got it about three parts full, boil the mercury so as to expel all the remaining air, and allow the thermometer to remain with its beak still under the mercury until it has cooled down nearly to the temperature of the room. Then bring up a beaker of cold water so that as much as possible of the thermometer is immersed, resting the beaker on another ring of the retort-stand. By means of a siphon change the water three times at intervals of five minutes. While this is going on counterpoise the crucible. We have now the thermometer full of mercury at the temperature, $t$, of the water, which we note. Take away the dish containing the mercury and replace it by the

[19] We must be careful to prevent the glass cracking by the contact of the cold mercury and the heated glass. The sides and not the bottom of the thermometer had better be heated first and the mercury in the dish warmed as well.

counterpoised crucible, so that it may catch any of the liquid that may be expelled from the thermometer. Now heat the water about 10° above the temperature of the room [20], keeping the water well stirred; note the temperature, $t_1$, and weigh the mercury expelled, $m_1$. Replace the crucible and heat again 10° higher: weigh the total quantity of liquid in the crucible, $m_2$: continue alternately heating and weighing thus till the water boils. Then take out the weight thermometer, dry it carefully, and find the mass, $M_n$, of the mercury it contains. Enter your results in a tabular form as follows :—

| Temperatures. | Mass of mercury in crucible. | Mass of mercury in weight thermometer. | Mean relative expansion of mercury. ($\Delta$) | Mean absolute expansion of mercury. ($\delta$) | Coefficient of expansion of glass. ($\delta - \Delta = k$) |
|---|---|---|---|---|---|
| $t$ | | $M$ | | | |
| $t_1$ | $m_1$ | $M_1$ | $\Delta_1$ | $\delta_1$ | $k_1$ |
| $t_2$ | $m_2$ | $M_2$ | $\Delta_2$ | $\delta_2$ | $k_2$ |
| ... | ... | ... | .. | ... | ... |
| $t_n$ | $m_n$ | $M_n$ | $\Delta_n$ | $\delta_n$ | $k_n$ |
| | | | | Mean = | . . . |

The numbers in the third column are obtained thus: the mercury contained in the weight thermometer at the beginning, $M$, is equal to $M_n + m_n$,

$$\therefore \quad M = M_n + m_n,$$
$$M_1 = M - m_1,$$
$$M_2 = M - m_2,$$
$$\text{\&c.}$$

To get the numbers in the fourth column let us find $\Delta_2$: $M_2$ c.c. of mercury evidently expand by $m_2$ c.c. for $(t_2 - t)°$,

$\therefore$ 1 c.c. expands by $\dfrac{m_2}{M_2(t_2 - t)^\circ}$ c.c. for 1°, which is $\Delta_2$, the mean coefficient of relative expansion between $t_2°$ and $t°$ (see

[20] Each time before taking the crucible away we must be sure the mercury is at the same temperature as the water. To ensure this regulate the flame

Experiment 13). The numbers in the fifth row are found from the tables (Appendix A. 2). The coefficient of expansion of glass is found by subtracting the corresponding numbers in the fourth and fifth rows.

***15. Determination of the coefficient of cubical expansion of a solid by the weight thermometer.**

*Apparatus.* A piece of fairly thick glass tubing about 15 cm. long and 1 cm. in diameter: Beaker: Thermometer: Evaporating Dish: Crucible: Retort-stand: Bunsen Burner: Glycerine: Leaden Shot.

*Experiment.* Close one end of the tubing in the flame, and introduce a known mass, $M_1$, of shot. Draw the other end out and bend as in Experiment 14. Weigh and determine the mass of the glass vessel. Fill it in the manner described in Experiment 14, using glycerine instead of mercury, being careful to get rid of all air bubbles. After it has attained the temperature, $t$, of the water in the beaker, replace the evaporating dish by a previously counterpoised crucible. Heat the water to boiling and continue boiling for five minutes, so that the shot may attain the temperature of the water. Note the temperature, $T$, of the boiling water. When no more glycerine is expelled weigh the crucible and determine the mass, $m$, of the glycerine in it. Then take the weight thermometer out of the water, dry it, and determine the mass, $M_2$, of the glycerine remaining in it.

On raising the temperature through $(T-t)^\circ$, $\tau^\circ$ suppose, the lead, glycerine, and glass have expanded, and the volume of the expelled glycerine evidently is equal to the sum of the expanded volumes of the lead and the glycerine less the expanded volume of the glass vessel.

If $D_1$ is density of Lead and $x$ its coefficient of cubical expansion,

so as to keep the temperature fairly constant for a minute, keeping the water well stirred. Before removing the crucible it is advisable to touch the beak of the weight thermometer with its side to detach any liquid adhering to the beak by capillary attraction.

if $D_2$ is density of Glycerine at $t°$ and $a$ its coefficient of cubical expansion,

and if $k$ is the coefficient of cubical expansion of the glass, then the volume of the Lead taken is

$$\frac{M_1}{D_1} = V_1 \text{ c.c., suppose,}$$

and the volume of the Glycerine that filled the weight thermometer at $t°$ is

$$\frac{M_2+m}{D_2} = V_2 \text{ c.c., suppose;}$$

$\therefore$ the volume of the glass vessel at $t°$ is $V_1+V_2$ c.c., and the volume of the expelled Glycerine at $t°$ is

$$\frac{m}{D_2} = v \text{ c.c., suppose.}$$

Therefore

$$v(1+a\tau) = V_1(1+x\tau)+V_2(1+a\tau)-(V_1+V_2)(1+k\tau),$$

$$\therefore \quad x = \frac{(V_1+V_2)k\tau+v(1+a\tau)-V_2a\tau}{V_1\tau}.$$

All the quantities on the right-hand side being known, we can determine $x$.

Determine as above the coefficients of expansion of iron and copper, both in the form of turnings.

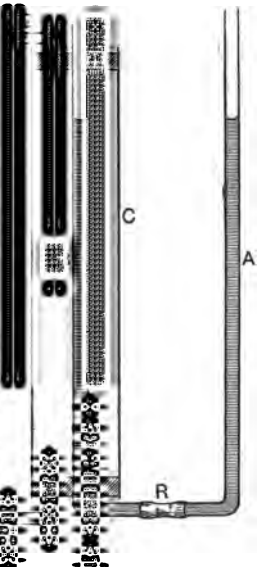
**16. Determination of the coefficient of absolute expansion of a liquid by Dulong and Petit's method.**

[*A* and *B* are two glass tubes, about ·75 cm. in internal diameter and 80 cm. in length, bent at right angles at the bottom where they are joined tightly together by a piece of india-rubber tubing *R*. *B* passes through two corks, closing the ends of a wide glass tube *C* about 3 cm. in diameter, and nearly but not quite as long as *B*[21]. Through these corks also pass two elbow tubes *D* and *E*—the upper one is connected with a boiling can (see note 12) and the lower one is to allow the escape of the steam. This apparatus should be fixed by pieces of leather to a wooden support.]

*Apparatus* (Fig. 7). Thermometer: Boiling Can: Bunsen Burner: Metre Rule: Amyl Alcohol.

[21] It is better to have the horizontal bend of *B* fused through the wall of the tube *C*, so that the whole column of the liquid may be heated by the steam, and then to measure the heights above the middle of the horizontal arm.

fit the elbow
by the tube
rmine so that




g. 7.

base of either
el. There are
the column in
lence *H* c.c. of
so that, if the
come *H*. The
heights, there-
pansion of the

Determine as above the coefficients of expansion of turpentine and glycerine.

**17. Determination of the coefficient of cubical expansion of a liquid by the bulb-tube.**

*Apparatus.* A long tube of narrow bore with a bulb at one end. (The tube must be graduated in equal divisions and the volume of the bulb and of a division must be known [Appendix B. 1.]) Beaker: Thermometer: Wire Gauze and Tripod: Bunsen Burner: Metre Rule: Turpentine.

*Experiment.* Fill the bulb and a small portion of the tube with turpentine and support it in a beaker of water resting on the wire gauze. Read the temperature, $t$, of the water and the division of the stem to which the turpentine reaches. Hence, knowing the volume of a stem division and also that of the bulb, calculate the total volume, $V$, occupied by the turpentine at $t^\circ$. Heat the water, keeping it continually stirred, up to a temperature at which the turpentine nearly fills the tube. Lower the flame and when the temperature has become constant read it, $T^\circ$ suppose, and calculate as before the total volume, $V'$, occupied by the turpentine when it ceases to rise. It is evident that the original volume, $V$, has expanded by $(V'-V)$, $v$ suppose, in excess of the expansion of the glass, for a rise of temperature $(T-t)^\circ$ [$\tau^\circ$ suppose].

$$\therefore \quad V \text{ c.c. expand by } v \text{ c.c. for } \tau^\circ,$$

$$\therefore \quad 1 \text{ c.c. expands by } \frac{v}{V\tau} \text{ c.c. for } 1^\circ,$$

which is the mean coefficient of relative expansion of turpentine between the two temperatures.

To get the mean coefficient of absolute expansion add to this the coefficient of cubical expansion of glass.

Determine as above the coefficients of expansion of glycerine and alcohol.

***18. Determination of the temperature at which water has the maximum density by Depretz' method.**

*Apparatus.* A bulb-tube similar to the one used in Experi-

ment 17, containing distilled water instead of Turpentine: Beaker: Thermometer: Wire Gauze on Tripod: Bunsen Burner: Curve paper: Ice.

*Experiment.* Support the bulb-tube in a beaker and pack it round with clean crushed ice and fill up the beaker with water. Place a thermometer in the ice, and when the mercury has reached its lowest point read the temperature. If the thermometer marks o°C as it should do if it were correct, it will give correct readings throughout the experiment; but, if it does not mark o°C, it will be necessary to correct the temperatures you observe during the experiment, adding to or subtracting from each the error of the freezing point according as the thermometer marks a temperature below or above o°C, while in the ice. When the water in the stem has become quite steady read the division, $n$, to which it reaches. Apply heat gently till the ice has melted, keeping it well stirred. At about every degree rise in temperature read the number of stem-divisions occupied by the water in the tube as well as the corresponding temperatures[22]. Knowing the volume of a stem-division and that of the bulb, calculate the total volumes occupied by the water at the different temperatures. Continue this till the water nearly fills the whole stem and enter your results in a tabular form as follows:—

| Vol. of Bulb = ... c.c.: vol. of a stem-division = ... c.c. | | | |
|---|---|---|---|
| Temperatures. | Number of stem-divisions occupied by the water. | Total volumes of the water. | Volumes to which 1 c.c. of water at o°C expands in excess of the glass. |
| o | $n$ | $V$ | 1 |
| $t_1$ | $n_1$ | $V_1$ | $\beta_1$ |
| $t_2$ | $n_2$ | $V_2$ | $\beta_2$ |
| ... | ... | ... | ... |

[22] To ensure that the liquid is at the temperature indicated, when it has been heated nearly to the temperature required, lower the flame so as to keep the temperature fairly constant for a minute. Now take the reading of the thermometer and the height of the liquid, when it ceases to rise.

To get the numbers in the fourth column divide those in the third by *V*. Plot your results on a curve, taking the temperatures as abscissae and the numbers in the fourth column as ordinates.

This curve gives us the expansion of water in excess of the glass bulb tube. What does the shape of the curve show? To get the absolute expansion of water we must first draw the curve of expansion of the glass. As we may consider its expansion to be uniform, the curve will be a straight line. Taking ·000026 as the coefficient of expansion of glass, multiply it by the highest temperature in column 1, and at the point in the line of abscissae representing this temperature, draw below the line an ordinate whose value is 1 + this product, and join its extremity with the origin. The vertical distance between this line and the original curve at any temperature gives us the volume which 1 c.c. of water at 0° would become at this temperature independently of the expansion of the glass vessel. Now draw a tangent to the original curve parallel to the line of glass expansion. The vertical distance between these two straight lines is evidently the smallest volume the water occupies, and the point where this vertical cuts the line of abscissae is therefore the temperature of maximum density of water [23].

## 19. Determination of the temperature at which water has the maximum density by Hope and Depretz' method.

[A cylindrical tin vessel *A* (a biscuit tin will do), about 10 cm. in height and 6 cm. in diameter, has four smooth holes bored at equal distances from each other, to which corks are fitted water-tight. Through each cork passes a thermometer. The cover *B* of the vessel is turned over and rests on the top, serving to contain the freezing mixture.]

*Apparatus* (Fig. 8). Ice: Salt: Curve-paper.

*Experiment.* Fill the vessel *A* quite full with distilled water and place as much of a freezing mixture of crushed ice and salt [1 part of salt to 2 parts of ice] as possible into the cover *B*. Replace the cover so that the bottom of it is in contact with the

[23] This experiment will, with care, give a good result.

surface of the water in *A*. Mark the temperatures indicated by the four thermometers every minute and arrange your results in a tabular form. No. 1 will cool rapidly at first since the water on cooling becomes denser and sinks to the bottom. No. 2 will cool more slowly, and No. 3 and 4 still more slowly until the lowest thermometer reaches the temperature of maximum density of water (about 4°). This one remains stationary while No. 2, 3, and 4 will in order arrive at this temperature. After this the water on further cooling expands, and being less dense No. 4, which was the last to reach 4°, will be the first to cool to 0°. The other thermometers, No. 3, 2, 1, will successively attain 0°. Plot on the same piece of curve-paper your results for the four thermometers, taking the times as abscissae and the corresponding temperatures for the ordinates. It will be found that the curves will cross each other along a horizontal line, which, on being continued, cuts the temperature axis at the temperature of the maximum density of water. It is important that the observer should not come closer to the apparatus than is absolutely necessary to read the thermometers, as the radiation from the body will prevent the water cooling sufficiently.

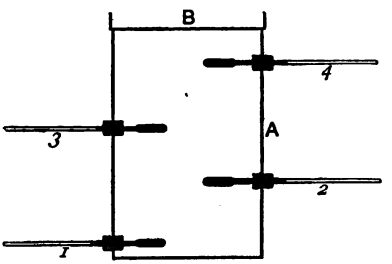


Fig. 8.

**20. Determination of the coefficient of cubical expansion of a liquid by the weight thermometer.**

*Apparatus.* Weight thermometer as in Experiment 14: Beaker: Thermometer: Evaporating Dish: Crucible: Retort-stand: Bunsen Burner: Glycerine.

*Experiment.* After counterpoising the weight thermometer fill it with glycerine according to the instructions of Experiment 14. When the glycerine is at the temperature, $t$, of the

water replace the evaporating dish by a previously counterpoised crucible. Heat the water, stirring continually, until it boils. Note the temperature, $T$, of the boiling water. Remove the crucible [Note 20] and find the mass of glycerine, $m$, that it contains. Take out the weight thermometer, dry it, and find the mass, $M$, of glycerine remaining in it. This glycerine will, on cooling, contract, and leave a space representing the volume of the expelled glycerine. Hence $M$ grams of glycerine at $t°$, on being heated to $T°$, would expand in excess of the glass by an amount represented by $m$ grams and would fill the weight thermometer. Taking, as we may, these masses as proportional to the volumes,

$M$ c.c. of glycerine expand in excess of the glass by $m$ c.c. for $(T-t)°$, [$\tau°$ suppose];

$$\therefore \quad 1 \text{ c.c. expands by } \frac{m}{M\tau} \text{ c.c. for } 1°,$$

which gives us the mean coefficient of relative expansion between these temperatures. To get the mean absolute expansion add the coefficient of cubical expansion of glass.

Determine as above the coefficient of expansion of turpentine.

***21. Determination of the coefficient of cubical expansion of mercury at different temperatures by the density bottle.**

*Apparatus.* Density Bottle: Beaker: Thermometer: Sand-bath: Bunsen Burner: Mercury: Curve-paper.

*Experiment.* Thoroughly clean and dry the density bottle. Counterpoise it and then fill it with clean dry mercury [Appendix B. 3, 4], while the density bottle is immersed up to its neck in water. Read the temperature, $t$, of the water. Take the bottle out and dry it, being careful not to handle it more than is absolutely necessary[24]. Find the mass, $M$, of the mercury it contains at this temperature. Replace the bottle in the beaker and gradually warm the water, stirring continually until the temperature has risen about 10°. When the mercury is at the

[24] See Note 17.

temperature of the water[25], read the thermometer, $t$, take the bottle out, dry it, and find the mass, $M_1$, of the mercury in it. Repeat this series of observations for about every 10° rise in temperature until the water boils. Note the temperature, $T$, of the boiling water, and enter your results in a tabular form as follows:—

| Temperatures. | Mass of mercury in bottle. | Mean coefficients of relative expansion. | Mean coefficients of absolute expansion. | Volumes to which 1 c.c. at $t°$ expands. |
|---|---|---|---|---|
| $t$ | $M$ | | | 1 |
| $t_1$ | $M_1$ | $\Delta_1$ | $\delta_1$ | $\beta_1$ |
| $t_2$ | $M_2$ | $\Delta_2$ | $\delta_2$ | $\beta_2$ |
| ... | ... | ... | ... | ... |

In order to get the numbers in the third column let us find $\Delta_2$. $M_2$ c.c. expand by $M-M_2$ c.c. in excess of the glass for a rise in temperature $(t_2-t)°$,

$$\therefore \quad 1 \text{ c.c. expands by } \frac{M-M_2}{M_2(t_2-t)} \text{ c.c. for } 1°,$$

which is $\Delta_2$, the mean coefficient of relative expansion of mercury between these temperatures. The numbers in the fourth column are obtained by adding the coefficient of cubical expansion of glass to those in the third column.

The numbers in the fifth column are found by dividing into $M$ the series of numbers in the second column: e.g.

$$M_2 \text{ at } t° \text{ expand to } M \text{ at } t_2°;$$

$$\therefore \quad 1 \text{ c.c. at } t° \text{ expands to } \frac{M}{M_2} \text{ [i.e. } \beta_2\text{] at } t_2°.$$

Plot a curve of your results, taking the temperatures as abscissae and the numbers in the fifth column as ordinates, and compare this curve with the similar one for water obtained in Experiment 18.

[25] See Note 22.

***22. Determination of the coefficient of cubical expansion of a liquid by Matthiessen's method.**

*Apparatus.* A balance with a hole bored in the base under one of the pans[26]. A piece of glass tubing about 4 cm. long: Beaker: Thermometer: Bunsen Burner: Glycerine.

*Experiment.* Hang the glass tube to one arm of the balance by a very fine wire, passing through the hole in the base of the balance, and arrange it so that it can dip into a beaker. Counterpoise the glass tube. Bring up a beaker of glycerine so as to immerse it completely, being careful not to let it touch the sides. Remove any air bubbles from it by a feather and note the temperature, $t$, of the glycerine. Restore equilibrium by known weights, $\omega_1$. This represents the weight of an equal volume of glycerine at $t°$. If $V$ is the volume of the glass tube, $d_t$ the density of glycerine at $t°$,

$$V d_t = \omega_1. \qquad (1)$$

Now heat the glycerine and allow the glass to remain in it until both are at the same temperature. Determine this temperature, $T$, and quickly restore equilibrium by known weights, $\omega_2$. If $k$ is the known coefficient of expansion of the glass, $d_T$ the density of glycerine at $T°$,

$$V(1+kT)\,d_T = \omega_2. \qquad (2)$$

Dividing (1) by (2) we have

$$\frac{d_t}{(1+kT)\,d_T} = \frac{\omega_1}{\omega_2}.$$

If $x$ is the mean absolute coefficient of expansion of glycerine

$$d_t = d_T\,(1+xT);$$

$$\therefore \quad \frac{1+xT}{1+kT} = \frac{\omega_1}{\omega_2};$$

$$\therefore \quad x = \frac{\omega_1(1+kT)-\omega_2}{\omega_2 T}.$$

[26] It is best if possible to have the balance at a sufficient height from the table to allow the beaker to rest on a piece of wire gauze on a tripod over a burner. By adjusting the flame of the burner we can keep the liquid at a fairly constant temperature while weighing.

Repeat the above twice more, raising the glycerine each time to a higher temperature. Enter your results in a tabular form and compare your values of $x$.

Determine as above the coefficients of expansion of Water and Amyl Alcohol.

***23. To find the change of volume produced on the melting of a solid.**

*Apparatus.* A piece of glass tubing about 25 cm. long: Beaker: Thermometer: Bunsen Burner: Mercury: Wax.

*Experiment.* Draw out one end of the glass tube to a point, and calibrate about 6 cm. of it from the other end [Appendix B. 2]. Bend the tube carefully 5 cm. from the pointed end so that the two branches are parallel. Counterpoise it and introduce through the pointed end a column of about 6 or 7 cm. of melted wax. Allow this to solidify and fuse the end with a blowpipe. If there is any air remaining melt the wax again and drive the air out by heat. Find the mass, $M$, of the wax introduced and determine its density, $D$: then its volume is $\frac{M}{D}$ (or $V$) cub. cm. Now pour into the tube some clean mercury until its level is about 5 cm. from the top. Immerse the tube in a beaker of water on a sand-bath so that all the wax is under the surface and support a thermometer near it. Heat the water, keeping it well stirred, up to the known melting point of wax. Directly it begins to melt read the level, $h_1$, of the mercury. Lower the flame and continue heating and stirring till the wax has all just melted. Read the level, $h_1'$, of the mercury again. This change of level represents a known change of volume $v_1$. Take away the burner and allow the wax to solidify. When it has just all solidified read the level of the mercury. Repeat this twice more: enter your results in a tabular form and take the mean change of volume as the correct result.

| Level of mercury when wax has | | |
|---|---|---|
| melted. | solidified. | Change of volume. |
| $h_1'$ | $h_1$ | $v_1$ |
| $h_2'$ | $h_2$ | $v_2$ |
| $h_3'$ | $h_3$ | $v_3$ |
| | Average | . . c.c. |

Original volume, $V = \ldots$ c.c.
Percentage change of volume on melting = ... %.

Determine as above the change of volume of Stearic Acid and of Ice on melting.

**24. Determination of the coefficient of cubical expansion of air at constant pressure (Method 1)[27].**

*Apparatus.* A piece of thermometer tubing about 20 cm. long: Beaker: Thermometer: Wire Gauze on Tripod: Bunsen Burner: Mercury: Curve-paper: Ice.

*Experiment.* Dry the thermometer tubing thoroughly: close one end of it in the flame. Dip the open end under the surface of clean mercury and heat it strongly with the Bunsen to drive out a portion of the air. On allowing it to cool, a thread of mercury will be forced up the tube, enclosing a certain volume of air. Tie this tube to a thermometer, placing the closed end opposite the zero. Support them vertically in a beaker on the wire gauze and pack them round with clean crushed ice, and fill up the beaker with water so that the whole column of air is under the surface. Read the temperature indicated by the thermometer and correct your subsequent readings for the error of freezing point, if any. Read also the volume, $v_0$, of the enclosed air in terms of the thermometer divisions. Replace the ice by tap-water and again read the volume of the enclosed air

[27] In this and the two following experiments we neglect the expansion of the glass.

and the temperature when both have become constant. Gently heat the water, keeping it constantly stirred, and about every 5° rise of temperature read the thermometer and the volume of the enclosed air. Take as many readings as the volume of the air will allow and enter your results in a tabular form as follows :—

| Temperature. | Volume of air. | Mean coefficient of expansion of air. | Volumes to which 1 c.c. at 0° expands. |
|---|---|---|---|
| 0 | $v_0$ | | 1 |
| $t_1$ | $v_1$ | $a_1$ | $\beta_1$ |
| $t_2$ | $v_2$ | $a_2$ | $\beta_2$ |
| ... | ... | ... | ... |

To get the numbers in the third column let us find $a_2$.

A volume $v_0$ c.c. at 0°C expands by $v_2 - v_0$ c.c. for a rise of temperature $t_2$°;

$\therefore$ 1 c.c. at 0°C expands by $\frac{v_2 - v_0}{v_0 t_2}$ c.c. for a rise of 1°C,

which gives us $a_2$, the mean coefficient of expansion of air between 0° and $t_2$°. To get the numbers in the fourth column divide those in the second column by $v_0$.

Plot your results on a curve, taking the temperatures as the abscissae and the corresponding numbers in the fourth column as the ordinates. What does the form of the curve show? Compare it with the curve obtained in Experiment 18.

**25. Determination of the coefficient of cubical expansion of air at constant pressure (Method 2).**

*Apparatus.* A round bottomed flask fitted air tight with a one-holed bung. Through the hole passes a piece of glass tubing to which is attached a short piece of india-rubber tubing. A vessel [in which to place the flask] containing a little water : Beaker : Thermometer : Litre measuring jar : Clip : Bunsen Burner.

*Experiment.* Thoroughly dry the flask, and after fitting the bung tightly into the neck support it inside the vessel so that it is just above the surface of the water. Cover with a piece of

cardboard through a hole in which the neck of the flask passes. Boil the water briskly for about 5 or 10 minutes, and, after reading the barometer, find the temperature, $T$, of boiling water. We now have the flask full of air at $T°$. Clip the india-rubber tubing, take the flask out of the vessel and invert it so that its neck dips under cold water. When the air has cooled open the clip. The water will rise in consequence of the contraction of the air. Shake the water up with the air for at least five minutes, until both are at the same temperature, keeping the neck of the flask under water. Then, arranging so that the level of the water inside and outside the flask is the same, i.e. so that the enclosed air is at atmospheric pressure, clip the india-rubber tubing in the same place as before and measure the volume, $v$, of the water that has entered and note its temperature, $t$. Then fill the flask with water up to the point where the india-rubber tubing was clipped in the first instance and measure its total volume, $V$.

It is evident that a volume $V-v$ c.c. of air at $t°$ would, on being heated to $T°$, expand to a volume $V$ c.c. and fill the flask. If $x$ is the coefficient of expansion of air

$$1 \text{ c.c. of air at } 0°\text{C becomes } 1+xt \text{ at } t°,$$

$$\text{and} \qquad 1+xT \text{ at } T°;$$

$$\therefore \quad V-v : V :: 1+xt : 1+xT;$$

$$\therefore \quad x = \frac{v}{(V-v)T-Vt},$$

which gives us the mean coefficient of expansion of air between these temperatures.

### 26. Determination of the coefficient of increase of pressure of air at constant volume.

[A glass tube with a bulb $B$ about 5 cm. in diameter, blown at one end, is bent twice at right angles as in the figure, the longer limb being from 40 to 45 cm. in length. All moisture must be carefully expelled from it by warming the bulb over a flame. The end of the tube is joined by a piece of india-rubber tubing[28] about 50 cm. long to another similar piece

[28] Thick india-rubber tubing lined with canvas ought to be used to withstand the pressure.

of glass tubing *A* about a metre in length. Fill the longer limb of *B*, the india-rubber tubing and part of the tube *A* with clean dry mercury. A small piece of paper is gummed on at '*a*' to serve as a mark. This apparatus should be attached by pieces of leather to a wooden support. Instead of using the india-rubber tubing a more convenient method is to join the ends of the two tubes by two branches of a thick india-rubber T-tube, the third branch being firmly bound to the nozzle of an ordinary india-rubber air ball. Pressure is exerted on the mercury filling the ball by a screw passing through a piece of wood resting on the ball, the opposite edge of the piece of wood being hinged to the base-board.

*Apparatus* (Fig. 9). Beaker: Thermometer: Metre rule: Bunsen Burner: Curve-paper: Ice.

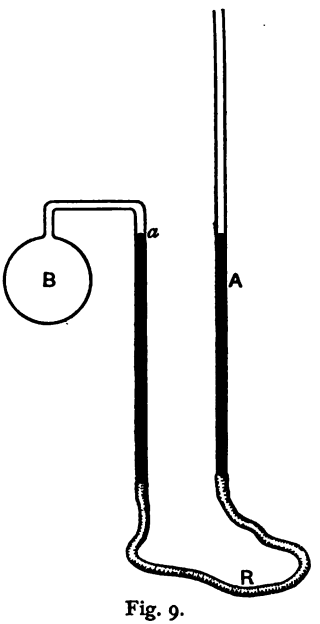


Fig. 9.

*Experiment.* Arrange the bulb *B* inside a beaker supported by wire gauze on a tripod, and pack it round with clean crushed ice and fill up the beaker with water. Raise or lower *A* so as to bring the level of the mercury exactly to the mark *a*. Read the temperature indicated by the thermometer and correct your subsequent readings for the error of freezing point, if any. Measure the difference of levels $h_0$, if any, of the mercury in the two tubes. Read the barometric height, *H*. The enclosed air is now at temperature 0° and under a pressure of $H \pm h_0$, according as the mercury in *A* is higher or lower than that in the other limb. Replace the ice by tap-water and wait until the temperature has become constant. The air will expand and press down the mercury below *a*. In order to reduce the air to the same volume as before, raise the tube *A* until the level of the mercury returns to *a*. At this instant

note the temperature, $t_1$, and simultaneously measure the difference, $h_1$, of the heights of the mercury columns[29]. Gently heat the water, keeping it continually stirred, and at about every 5° rise in temperature reduce the air to its original volume and note simultaneously the temperature and the difference of the heights of the mercury columns. Take as many readings as possible, and enter your results in a tabular form as follows:—

Barometric height, $H$ = ... mm.

| Temperatures. | Difference in heights of mercury columns. | Pressure of enclosed air. | Mean coefficient of increase of pressure. |
|---|---|---|---|
| 0 | $h_0$ | $H \pm h_0 = P_0$ | |
| $t_1$ | $h_1$ | $H + h_1 = P_1$ | $a_1$ |
| $t_2$ | $h_2$ | $H + h_2 = P_2$ | $a_2$ |
| ... | ... | ... | ... |

To get the numbers in the fourth column, let us find $a_2$.

The pressure $P_0$ at 0° increases to $P_2$ for a rise of temperature $t_2$,

∴ unit pressure at 0° increases by

$$\frac{P_2 - P_0}{P_0 t_2} \text{ or } \frac{h_2 - h_0}{P_0 t_2} \text{ for a rise of } 1°,$$

which gives us $a_2$ the mean coefficient of increase of pressure between these temperatures.

Plot your results in a curve, taking the temperatures as abscissae and the corresponding pressures in the third column as ordinates, and compare with the curve in Experiment 24.

We have assumed that the small volume of air in the short branch tube between the level of the water in the beaker and the mark *a* is at the same temperature as the air in bulb. For greater accuracy we should have to allow for this not being so.

N.B. When you have finished be careful to lower *A* as far as it will go, as otherwise, when the air cools, mercury will be forced into the bulb.

***27. Determination of the boiling-point of a saline solution by the air thermometer.**

*Apparatus.* A perfectly dry Flask about 300 c.c. capacity

[29] See Note 22.

with its neck drawn out to a fine point: Large Beaker, containing a saturated solution of Common Salt[30]: Sand-bath: Bunsen: Thermometer.

*Experiment.* Weigh the flask to determine its mass. Support it so that it is almost completely immersed in the saline solution. Boil the solution for about five minutes, then fuse the pointed neck of the flask with a blowpipe flame. Take it out, wash the outside and place its neck under water, and, when sufficiently cool, break off the point. The air inside will contract on cooling and water will enter the flask. Shake up the water and air for five minutes, keeping the neck under the surface. When the flask and the water have attained the same temperature, $t$, which we must determine with a thermometer[31], arrange it so that the level of the water inside and outside the flask is the same, close the point with the finger, and take it out of the water. Dry it and weigh, and find the mass of water that has entered by subtracting the mass of the empty flask. This mass in grams may be taken to represent the volume, $v$, of the water that has entered.

Now carefully boil the water in the flask for a minute or two, and then quickly dip its neck under water. If it has been boiled long enough, all the air will have been expelled, and water will enter and fill the flask. After allowing the whole to cool, take it out, dry, and re-weigh, and so determine the mass of water that fills the flask which may be taken to be its volume, $V$ c.c. A volume $V-v$ c.c. of air at $t°$ would on being heated to the temperature, $T$ suppose, of the boiling saline solution expand to a volume $V$ c.c. and fill the flask. If $a$ is the known coefficient of expansion of air we have, as in Experiment 25,

$$V-v : V :: 1+at : 1+aT;$$

$$\therefore \quad T = \frac{Vat+v}{a(V-v)}.$$

Determine as above the boiling point of oil and of a saturated solution of Copper Sulphate.

[30] 100 grs. of water dissolve 36 grs. of common salt at 15°.

[31] The error of freezing point of the thermometer should have been determined as in Experiment 4 and the proper correction applied to the temperature, $t$.

## C. Calorimetry.

The unit of heat, called a *calorie*, is that quantity of heat which is required to raise 1 gram of water one degree centigrade. We shall assume that this is constant all through the scale of temperatures.

The *specific heat* of a substance is the ratio of the quantity of heat required to raise a given mass of the substance through a certain number of degrees to the quantity required to raise an equal mass of water through the same number of degrees—in other words, it represents the number of calories, as defined above, required to raise 1 gram of the substance 1°C, or the number emitted by 1 gram when cooling 1°C.

*The heat of fusion* is the quantity of heat required to transform 1 gram of a solid to the liquid state at the same temperature, or *vice versâ*. *The heat of vaporisation* is the quantity of heat required to transform 1 gram of a liquid to vapour at the same temperature, or *vice versâ*, under given atmospheric pressure.

N.B. In the following experiments on the measurements of quantities of heat, we must arrange to lessen as much as possible conduction and radiation of heat from the calorimeter—the vessel in which heat is measured. To prevent conduction the calorimeter may either be supported on a triangle of cord tied to a ring of the retort-stand, or may be packed in an empty beaker with cotton wool, or better still, be supported by strings inside a tin vessel.

The methods by which the errors due to radiation are corrected are beyond the scope of this book, and therefore we must try and lessen the amount of radiation. This may be done by polishing the outside of the calorimeter and the inside of the tin vessel in which it is placed, and also by placing so much liquid in the calorimeter that the final temperature may not be much above the temperature of the room. We shall assume that the above precautions are taken in each of the following

experiments in Calorimetry. When two thermometers are used they must always be compared, either as in Experiment 3 or by dipping them into the same beaker of water, and the reading taken on one must be reduced to what it would be on the other.

**28. Determination of the water value of the Calorimeter and Thermometer.**

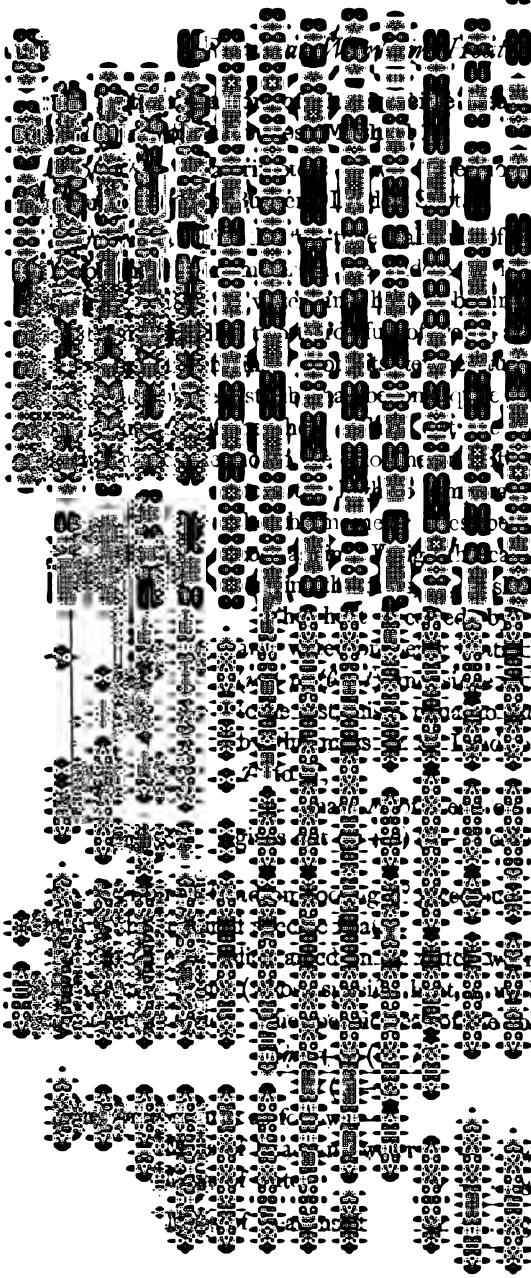
*Apparatus.* A metal vessel to be used as a Calorimeter: Beaker: Two Thermometers: Sand-bath: Bunsen Burner.

*Experiment.* Counterpoise the calorimeter, and support a thermometer with its bulb inside the vessel. Heat some water in a beaker to about 25° or 30°C, and take its temperature, $T$, with the other thermometer. Let the temperature of the calorimeter be $t°$. Quickly pour some of the warm water into the calorimeter so that it is about half full. Stir well and read the highest temperature, $\theta$, to which the thermometer rises before it begins to cool again. Weigh and find the mass, $m$, of water that has been poured in.

$m$ grams of water have cooled from $T°$ to $\theta°$, therefore they have given out $m(T-\theta)$ calories. Since no heat is supposed to be lost, these have been absorbed by the calorimeter and thermometer, raising their temperature from $t°$ to $\theta°$ $\therefore$ $\frac{m(T-\theta)}{\theta-t}$ calories would raise them 1°C. This quantity is called their '*water value*' or '*heat capacity*'[32]. It is evidently equal to the number of grams of water that would have been raised the same number of degrees.

Repeat this experiment, using water that has been heated to 70°, and enter your results in a tabular form.

[32] In the following experiments the water value of the calorimeter and thermometer is denoted by $\mu$. If we know the specific heat of the material of which the calorimeter is made we can find its water value by multiplying its mass by its specific heat.



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ries;

$$\frac{(m+\mu)(\theta-t)}{M(T-\theta)},$$

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rs.

Water value of the calorimeter and thermometer $\mu = \ldots$ grs.

| | | | |
|---|---|---|---|
| Final temp. of water and cal. | $= \ldots^\circ$ | original temp. of Lead | $= \ldots^\circ$ |
| Original do. | $= \ldots^\circ$ | Final do. | $= \ldots^\circ$ |
| Rise of temp. of do. | $= \ldots^\circ$ | Fall of temp. of do. | $= \ldots^\circ$ |

Number of calories absorbed by water $= \ldots$

" " " " " cal. and therm. $= \ldots$

Total number of calories absorbed by the water, cal., and therm. which is equal to the total number emitted by the Lead $= \ldots$

$\therefore$ ... grs. of Lead on cooling ...° emit ... calories.

$\therefore$ 1 gr. " " " " 1° emits ... calories.

N.B. This may be taken as a type for tabulating the results of experiments in Calorimetry.

Determine as above the specific heats[38] of Copper, Tin, Zinc, Crystallised Copper Sulphate [in Turpentine whose specific heat must be determined as in Experiment 34].

[Instead of heating the solid in a test-tube in a beaker of water, by which method some heat is lost while transferring the solid to the calorimeter, a better plan would be to use the apparatus of Fig. 10. *B* is a glass tube 9 cm. long and 1·5 cm. in diameter, closed at one end by a cork, through which passes a thermometer *T*. This tube passes through two corks closing the ends of a wider glass tube *A*, 10 cm. long and 4 cm. in diameter. Two elbow-tubes pass through the corks of *A*, the upper one *C* being connected with a boiling can, the lower one *D* allowing the steam to escape. The solid is hung by a thread close to the bulb of the thermometer. Steam is passed through the outer cylinder till the thermometer rises no more. By raising the cork we allow the solid to drop into the calorimeter placed under the tube *B*.]

### 30. Determination of the specific heat of a solid by the method of mixtures (Method 2).

*Apparatus.* Calorimeter: Beaker: Two Thermometers: Wire cage: Bunsen Burner: Beeswax.

[38] The solid should either be in small pieces, in powder, or in sheet.

*Experiment.* In the case of a solid lighter than water, or of one that sticks to the test-tube on being heated, take a small open wire cage, whose specific heat, $s$, is known and find its mass, $m'$. Cut up the solid into small pieces and place them in the cage. Weigh to determine the mass, $M$, of the solid. Hang the cage containing the solid by a thread in water which we raise to a temperature, $T$, below the known melting point of the solid. Counterpoise the calorimeter and fill it two-thirds full of water. Find the mass, $m$, of water introduced and determine its temperature, $t$. Quickly transfer the cage to the calorimeter, note the final temperature, $\theta$, and weigh again to determine the mass, $m''$, of water that was carried over. Then since the heat given out by the solid, the cage, and water, $m''$, is equal to the heat received by calorimeter, thermometer and water, $m$, we have, if $x$ is specific heat of the solid,

$$[Mx+m's+m''](T-\theta)=(m+\mu)(\theta-t);$$

hence we determine $x$.

N.B.—Since the amount of water carried over is usually very small, we may, unless great accuracy is required, omit the final weighing and neglect $m''$.

Determine as above the specific heat of Paraffin-wax.

**31. Determination of the specific heat of a solid by fusion of ice.**

*Apparatus.* Beaker: Test-tube: Thermometer: Bunsen Burner: Cotton wool: Small block of Ice: Small piece of Lead.

*Experiment.* Weigh the piece of lead, $M$, and put it and a thermometer in a test-tube immersed in a beaker of water. Heat the water to boiling. Counterpoise a small piece of cotton wool attached to a piece of glass tube as a handle. Bore out a hole in the block of ice and carefully dry it. When the thermometer in the test-tube has become quite stationary read the temperature, $T$, and quickly transfer the lead to the hole in the ice. Let it remain till it has cooled to 0°. Then sop up with the cotton wool the water that is formed. Weigh the

cotton wool and determine the mass, $m$, of the ice that has melted. One gram of ice requires 79·25 calories to melt it, therefore 79·25 $m$ calories have been given out by $M$ grams of lead in cooling from $T°$ to 0°, therefore 1 gram of lead would give out $\frac{79{\cdot}25\,m}{MT}$ calories on cooling 1°, which is the required specific heat.

Determine as above the specific heats of Copper and Iron, and compare your results with those obtained in Experiment 29.

**32. Determination of the specific heat of a liquid by the method of mixtures (Method 1).**

*Apparatus.* Calorimeter: Beaker: Thermometer: Bunsen Burner: Mercury.

*Experiment.* Counterpoise the calorimeter and pour in water[34] until it is about two-thirds full. Find the mass, $m$, of the water added and place a thermometer in it. Put some mercury in a vessel with a thermometer and heat it to about 100° *C.* Note the temperature, $T$, of the mercury, and also the temperature, $t$, of the water. Quickly pour some of the mercury into the calorimeter and, stirring the mixture together, note the highest temperature, $\theta$, to which the thermometer rises. Weigh the calorimeter and determine the mass of mercury, $M$, introduced.

The water and the calorimeter have been heated from $t°$ to $\theta°$, and have therefore absorbed $(m+\mu)(\theta-t)$ calories. Since no heat is supposed to be lost, this is the number of calories given out by $M$ grs. of mercury cooling from $T°$ to $\theta°$.

$\therefore$ $M$ grs. of mercury, cooling $(T-\theta)°$, give out $(m+\mu)(\theta-t)$ calories.

$\therefore$ 1 gr. of mercury, cooling 1°, gives out $\frac{(m+\mu)(\theta-t)}{M(T-\theta)}$ calories, which is the required specific heat.

Determine as above the specific heat of Turpentine, and of a 15 per cent. solution of Ammonium Chloride, and of a 20 per cent. solution of Sodium Chloride.

[34] If the liquid, whose specific heat is required, is lighter than water, it should be put in the calorimeter and the water should be heated.

**33. Determination of the specific heat of a liquid by the method of mixtures (Method 2).**

*Apparatus.* Same as for Experiment 32, and, in addition, Alcohol.

*Experiment.* In the case of a liquid, e.g. Alcohol, which emits or absorbs heat on being mixed with water, we cannot determine its specific heat as above, but instead of water must use some liquid, e.g. Turpentine, whose specific heat, $s$, is known, which has no action on the given liquid. Counterpoise the calorimeter and fill it half full of Alcohol. Determine the mass, $M$, of the Alcohol and its temperature, $t$. Heat some Turpentine[35] to about 60°, note its temperature, $T$, and pour some into the calorimeter. Determine as before the final temperature, $\theta$, to which the mixture rises. Weigh to determine the mass, $m$, of Turpentine added. The heat given out by the Turpentine on cooling from $T°$ to $\theta°$ is equal to the heat absorbed by the Alcohol and calorimeter on being heated from $t°$ to $\theta°$. Therefore,

$$ms(T-\theta) = (Mx+\mu)(\theta-t),$$

whence $x$, the required specific heat of alcohol, can be determined.

**34. Determination of the specific heat of a liquid by the method of mixtures (Method 3).**

*Apparatus.* Calorimeter: Beaker: Two Thermometers: Bunsen Burner: Turpentine: Leaden Shot.

*Experiment.* Instead of using a second liquid as in Experiments 32 and 33 we may use a solid, such as Lead, whose specific heat, $s$, is known. Having poured into the calorimeter a known mass, $M$, of Turpentine whose temperature, $t$, we determine, put some of the shot into a test-tube with a thermometer and place it in a beaker of water which we heat to boiling. When the thermometer stops rising read the temperature, $T$, of the lead and quickly transfer it to the calorimeter and, stirring, note the final temperature, $\theta$.

[35] The vessel should be nearly full of Turpentine, so that but little heat is lost on pouring it into the calorimeter.

Weigh the calorimeter and find the mass, $m$, of shot introduced. The lead on cooling from $T°$ to $\theta°$ gives out $ms\,(T-\theta)$ calories of which $\mu\,(\theta-t)$ have gone to heat the calorimeter, therefore $ms\,(T-\theta)-\mu\,(\theta-t)$ have heated $M$ grams of Turpentine from $t°$ to $\theta°$;

therefore $$\frac{ms(T-\theta)-\mu(\theta-t)}{M(\theta-t)}$$

calories would heat 1 gram of Turpentine 1°, which is the required specific heat.

Determine as above the specific heats of Glycerine, of Alcohol, and of concentrated Sulphuric Acid.

### 35. Determination of the specific heat of a liquid by the method of cooling[36].

*Apparatus.* Calorimeter[37]: Beaker: Thermometer: Bunsen Burner: Mercury.

*Experiment.* Counterpoise the calorimeter and support it on a triangle of strong cord tied to the ring of a retort stand. Heat some clean dry mercury up to about 70° or 80°, and pour some of it into the calorimeter so as to fill it about half full. Put the thermometer in the mercury[38], and while stirring carefully observe the time it takes to cool every 5° down to 40°. Weigh calorimeter and find mass, $M$, of mercury in it. Empty the mercury out and repeat exactly the same series of observations with water instead, being careful to fill the calorimeter with the water to the same height as the mercury was at. Let $m$ be the mass of water introduced.

To determine the specific heat from our observations we must remember that Dulong and Petit proved by experiment that when two different liquids are allowed to cool in an enclosure of a constant temperature, the velocity with which either loses heat only depends on the excess of its temperature over that of

[36] This method gives satisfactory results only with liquids which are good conductors of heat.

[37] When mercury is used the calorimeter must not be of tin. In this case a glass beaker may do. We must determine its water value as before.

[38] See Note 6.

the enclosure and on the nature and extent of the surface at which the cooling takes place, and is independent of the nature of the liquid. Therefore, since we fill the same calorimeter to the same height in both cases, the quantity of heat given out per minute by the mercury and the water must be the same between the same range of temperatures. If $M$ is the mass of mercury and if it takes $n_1$ minutes to cool 5°, the heat given out per minute is

$\frac{5(Mx+\mu)}{n_1}$, where $x$ is the specific heat of mercury.

The heat lost per minute by a mass $m$ of water which takes $n_1'$ minutes to cool through the same 5° is

$$\frac{5(m+\mu)}{n_1'}.$$

Equating the above two expressions we determine $x$, the required specific heat.

Enter your results in a tabular form as follows:—

| Temperature. | Time of cooling. | | Specific heat of mercury. |
|---|---|---|---|
| | Mercury. | Water. | |
| 70°–65° | $n_1$ | $n_1'$ | $x_1$ |
| 65°–60° | $n_2$ | $n_2'$ | $x_2$ |
| ... | ... | ... | ... |
| | | Mean = | ... |

Mass of water, $m$ = ... grs.
Mass of mercury, $M$ = ... grs.

Determine as above the specific heat of Glycerine.

**36. Determination of the quantity of heat absorbed or emitted when a salt is dissolved in water.**

*Apparatus.* Calorimeter: Beaker: Thermometer: Powdered Ammonium Chloride.

*Experiment.* Counterpoise the calorimeter and pour into it

100 grams or cub. cm. of water whose temperature, $t$, we note. Weigh about 15 grams of Ammonium Chloride and transfer it to the calorimeter. Keep stirring the mixture and read the lowest temperature, $\theta$, to which the thermometer sinks. Then weigh the calorimeter and determine the exact mass, $m$, of the salt introduced.

The quantity of heat absorbed cooled the solution, whose known specific heat is $s$, and the calorimeter from $t°$ to $\theta°$, therefore the heat absorbed by dissolving 1 gram of Ammonium Chloride in 100 grams of water is

$$= \frac{[(100+m)s+\mu](t-\theta)}{m},$$

which is called the 'Heat of Solution' of the solid.

Determine as above the heat of solution of Sodium Chloride.

N.B. Specific heat of a 15 per cent. solution of Ammonium Chloride is ·89.

Specific heat of a 20 per cent. solution of Sodium Chloride is ·86.

In both cases the alteration per cent. of the specific heat may be taken as ·005.

### 37. Determination of the Heat of Fusion of Ice.

*Apparatus.* Calorimeter: Beaker: Thermometer: Ice.

*Experiment.* Counterpoise the calorimeter and fill it three parts full of water whose mass, $m$, we determine. The water may with advantage be warmed 5° above the temperature of the room, so that the heat it radiates in the first part of the experiment may be compensated by the heat it absorbs in the latter part. Support a thermometer in it and note its temperature, $t$. Clean a piece of ice and break it up into small pieces and transfer them one by one to the calorimeter, after brushing off the moisture from them, by a pair of crucible tongs whose points are wrapped in flannel. Be careful not to put so much ice in that it cannot all be melted. For 50 grams of water at 15°, 4 cub. cm. of ice will be sufficient. Keep stirring the ice with the water until it is all melted, and note the lowest

temperature, $\theta$, to which the thermometer sinks. Weigh the calorimeter and determine the mass, $M$, of ice introduced. The water and calorimeter have been cooled from $t°$ to $\theta°$; the amount of heat given out by them is therefore

$$(m+\mu)(t-\theta).$$

Part of this has gone to melt the ice and part to raise the resulting water from 0 to $\theta$. The latter quantity is $M\theta$, therefore the amount gone to melt the ice is

$$(m+\mu)(t-\theta)-M\theta,$$

therefore 1 gram of ice requires $\dfrac{(m+\mu)(t-\theta)-M\theta}{M}$ to melt to 1 gram of water at 0°, which is the required heat of fusion.

**38. Determination of the heat of Fusion of a solid (Method 1).**

*Apparatus.* Calorimeter: Beaker: Two Thermometers: Bunsen Burner: Paraffin-wax.

*Experiment.* Counterpoise the calorimeter. Place in it about 5 grams of paraffin-wax whose specific heat, $s$, is known, and find its mass, $M$. It is best to melt the wax first, and by shaking cause it to be deposited in a thin layer on the inner surface of the calorimeter. The whole must of course be allowed to cool completely before proceeding with the experiment. Heat some water in a beaker up to about 70°. Place a thermometer in the calorimeter and determine its temperature, $t$. Read the temperature[39] of the hot water, $T$, and pour enough of it into the calorimeter to fill it two-thirds full; keeping it stirred, read the temperature, $\theta$, to which the thermometer rises before it begins to cool slowly by radiation. Now weigh the calorimeter and find the mass, $m$, of water that has been poured in. The hot water has given out $m(T-\theta)$ calories, of which $(Ms+\mu)(\theta-t)$ have been absorbed by calorimeter and wax in being heated from $t°$ to $\theta°$.

[39] The temperature must be such that the final temperature $\theta$ is above the melting-point of the solid.

$\therefore$ $m(T-\theta)-(Ms+\mu)(\theta-t)$ have been used to melt the wax, therefore 1 gram of wax requires

$$\frac{m(T-\theta)-(Ms+\mu)(\theta-t)}{M}$$

to melt it, which is the required heat of fusion.

N.B.—In this experiment we assume that the specific heat of wax in the solid and the liquid state is the same. This assumption is by no means a legitimate one, and in the following experiment the error thus introduced is eliminated.

***39. Determination of the heat of Fusion of a solid (Method 2).**

*Apparatus.* Same as in Experiment 38.

*Experiment.* If the specific heat of the substance in the liquid state is not known, we can, by performing two experiments similar to Experiment 38, in which the masses of the wax and the water, as well as the original temperature of the water are different, determine not only the latent heat but also the specific heat of the substance in the liquid state.

Suppose $\phi$ is the melting point of the solid,

$s$ the specific heat of the substance in the solid state,

$s'$ the specific heat of the substance in the liquid state,

and $x$ the heat of fusion of the solid.

If in the first experiment we take $m$ grams of water at $T^\circ$ and $M$ grams of the solid at $t^\circ$, and find the resulting temperature $\theta$, then since the heat given out by the water is equal to the heat which raises the calorimeter and solid from $t^\circ$ to the melting point, and melts the solid at this temperature and then raises the liquid and the calorimeter to $\theta^\circ$, we have

$$(Ms+\mu)(\phi-t)+Mx+(Ms'+\mu)(\theta-\phi)=m(T-\theta). \quad (1)$$

By taking in a second experiment $M'$ grams of the solid and $m'$ grams of hot water at $T'^\circ$, supposing $\theta'^\circ$ to be the resulting temperature, we have

$$(M's+\mu)(\phi-t)+M'x+(M's'+\mu)(\theta'-\phi)=m'(T'-\theta'). \quad (2)$$

we can find by

wax.

**ion of water.**

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closing one end of
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5 cm. in diameter.
also tightly closed
which passes a
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lower end is con-
dia-rubber tubing
of glass tubing.]

(Fig. 11). Calori-
meter: Bunsen

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two-thirds full
ater. When the
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meter and let the
steam to pass
temperature has
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the calorimeter
ed. Note baro-
of the boiling
ve risen from $t^\circ$
ories. The con-
g out $M(T-\theta)$
by $M$ grams of

steam condensing to water at $T°$ is $(m+\mu)(\theta-t)-M(T-\theta)$. The amount that one gram of steam gives out on condensing to water at $T°$ is therefore

$$\frac{(m+\mu)(\theta-t)-M(T-\theta)}{M},$$

which is the required heat of vaporisation of water.

**41. Determination of the heat of vaporisation of alcohol.**

*Apparatus.* Same as in Experiment 40 with addition of Alcohol.

*Experiment.* As alcohol mixed with water emits heat we must pass the vapour into alcohol instead of into water. Fill the flask half full of alcohol and raise it to its known boiling point $T$. Fill the calorimeter half full of alcohol and determine the mass, $M$, introduced, and also its temperature, $t$. Proceeding in a similar way as in Experiment 40 we pass the vapour into the alcohol and note the final temperature, $\theta$, which must be below the boiling point of alcohol, and determine the mass, $M$, of alcohol vapour condensed. This weighing should be done as quickly as possible, as loss by evaporation occurs. Then, if $s$ is the known specific heat of alcohol and $x$ is latent heat, we have

$$Mx+Ms(T-\theta)=(ms+\mu)(\theta-t),$$

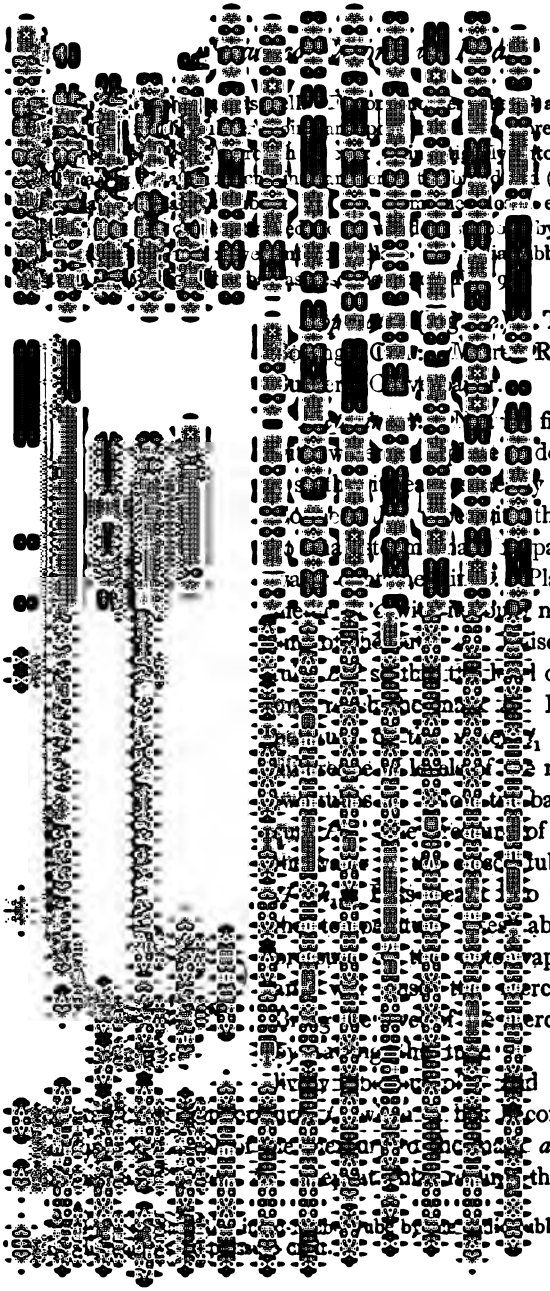
whence we can determine $x$, the heat of vaporisation required.

## D. Evaporation.

**42. Determination of the pressure of aqueous vapour at temperatures below 100° C.**

[Take a thick glass tube $A$ closed at one end about 50 cm. in length and ·75 cm. in diameter. To the other end attach a piece of thick india-rubber tubing[41] $R$ about 50 cm. long, and fill both glass and rubber-tubing with clean dry mercury up to within about 2 cm. of the open end. Fill the empty part with distilled water. Pinch the india-rubber tube, and raise the glass tube so that the water passes to the closed end, being careful that

[41] Thick india-rubber tubing lined with canvas ought to be used to withstand the pressure.



about a metre in
e mercury. Pass
to the neck of a
(Appendix B. 5).
end of *A*. This
by leather bands.
bber tubing by a

Thermometer :
Rule : Bunsen

fill the jar *C*
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to the bottom.
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Place a thermo-
near the closed
se or lower the
of the mercury
Read the tem-
$t_1$ and also the
mercury in the
barometric pres-
of the vapour of
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to the jar *C* until
about 5°. The
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ercury back to *a*
Take the de-
and stir the water,
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*a* and read the
the temperature

bber ball we must

each time about 5° until the water boils, and enter your results in a tabular form as follows:—

Barometric height, $H$ = ...mm.

| Temperatures. | Difference of levels. | Pressure of vapour. |
|---|---|---|
| $t_1$ | $h_1$ | $H-h_1$ |
| $t_2$ | $h_2$ | $H-h_2$ |
| ... | ... | ... |

Plot your results in a curve, taking the temperatures as abscissae and the corresponding pressures as ordinates.

N.B. To obtain a more accurate result we ought to allow for the fact that the upper portion of the mercury column of $A$ which is immersed in the water is at a higher temperature than the rest of the mercury. Suppose at any given excess of temperature $\tau$ the difference of levels between $A$ and $B$ is $h$, of which the length $h'$ is outside and $h''$ in the water. If $\delta$ is the mean coefficient of absolute expansion of mercury at $\tau°$, $h''$ would become $\frac{h''}{1+\delta\tau}$ when reduced to the temperature of the room, therefore the corrected difference of level would be

$$h' + \frac{h''}{1+\delta\tau} = h' + h''(1-\delta\tau) \text{ approximately,}$$
$$= h' + h'' - h''\delta\tau = h - h''\delta\tau.$$

We should have therefore to subtract from the numbers in the second column a length obtained by multiplying the height of '$a$' above the cork by $\delta$, and by the corresponding excess of the temperature of the water above the room.

**43. Determination of the pressure of aqueous vapour at temperatures above 100° C.**

*Apparatus.* Round-bottomed flask fitted with a two-holed bung: Glass tubing 50 cm. long: Narrow Glass Jar about 30 cm. high: Thermometer: Retort-stand: Bunsen Burner: Half Metre Rule: Sand-Bath: Mercury: Curve-paper.

*Experiment.* Bend the glass tube at right angles about 5 cm. from one end. Ten centimetres from this bend, bend it again at right angles in same direction. Fit the shorter limb into a hole of the bung: into the other hole push the thermometer so that its bulb nearly touches the surface of the water with which the flask is half filled. Put in the flask a small piece of clean coke to prevent boiling with bumping. Tie down the bung to prevent its being forced out by the pressure of the steam. Place the flask on a sand-bath on a ring of the retort-stand at a convenient height. Arrange the lower end of the bent tube so that it nearly touches the bottom of the gas jar. Boil the water, and noting the barometric height, $H$, find the temperature, $T$, at which it boils. Pour into the jar some mercury until its level is about 2 cm. from the bottom. The tube should touch the side of the jar so that its end may be seen through the glass. Heat the water again until it boils[43]. Note the temperature $T_1$, and measure the distance $h_1$ of the surface of the mercury above the open end of the tube. The temperature, $T_1$, is the boiling point under a pressure $H+h_1$. Repeat this process, adding nearly equal quantities of mercury each time. Enter your results in a tabular form as follows:—

Barometric height, $H=\ldots$ mm.

| Boiling points. | Heights of mercury above end of tube. | Pressures. |
|---|---|---|
| $T$ | 0 | $H$ |
| $T_1$ | $h_1$ | $H+h_1$ |
| $T_2$ | $h_2$ | $H+h_2$ |
| ... | ... | ... |

Plot a curve, taking the boiling points as abscissae, and corresponding pressures as ordinates.

[43] If a considerable quantity of steam condenses on the mercury it may be occasionally got rid of by means of a large pipette.

***44. Determination of the pressure of alcohol vapour at different temperatures.**

[*A*, a flask of about 300 c.c. capacity with rather a wide neck, is fitted with an air-tight cork. Through this passes one end of a U-tube *C* about ·5 cm. in diameter, bent as in the figure, the longer limb of which is about 30 cm., the shorter about 15 cm. in length. Through the cork also passes a piece of wide glass-tubing *B* about 6 cm. in length and ·75 cm. in diameter, the ends of which are closed by smooth plugs of cork [44].]

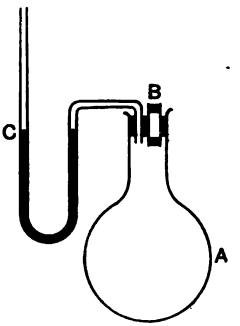

Fig. 13.

*Apparatus* (Fig. 13). Beaker: Thermometer: Half Metre Rule: Bunsen Burner: Wire Gauze on Tripod: Alcohol: Curve-paper.

*Experiment.* Pour into the tube *C* sufficient clean mercury to fill it nearly to the level of the horizontal branch. Fit it to the cork, and fit the cork tightly into the flask. Place the flask in a beaker of water on a piece of wire gauze on a tripod and note the temperature, $t_1$. Read off the difference of levels, if any, $h$, of the mercury, and note the barometric pressure, $H$. The pressure of the air in the flask is $H \pm h$, according as the level in the shorter arm is below or above that in the longer arm. Let this pressure be $P_1$. The next step will be to introduce some alcohol into the flask without opening any communication with the external air. To do this take out the upper plug from the tube *B* and nearly fill the latter with alcohol. Replace the plug and push it down the tube. As the alcohol is compressed it will force out the lower plug and drop into the flask and will saturate the space with its vapour. Read off the difference of levels of the mercury $h_1$. Then $H + h_1$ gives us the pressure of the alcohol vapour and air at $t_1$. Therefore $h_1 - h$ is the pressure, $p_1$, due to the alcohol alone. Heat the water gradually, keeping it well stirred until the thermometer rises about 5°. Read the temperature, $t_2$, and the difference of levels, $h_2$ [45]. Then $H + h_2$ gives the pressure of the alcohol vapour and

[44] The plugs cut out by the usual cork-borers in making holes through a cork will do very well, if smoothly cut.

[45] See Note 22.

air. Continue heating and reading the thermometer and difference of levels for every 5° rise of temperature until the thermometer marks 50°. Enter your results in a tabular form as follows :—

Barometric height, $H$=...mm.

| Temperature. | Difference of levels. | Pressure of alcohol + air. | Pressure of air. | Pressure of alcohol. |
|---|---|---|---|---|
| $t_1$ | $h_1$ | $H+h_1$ | $P_1$ | $p_1$ |
| $t_2$ | $h_2$ | $H+h_2$ | $P_2$ | $p_2$ |
| $t_3$ | $h_3$ | $H+h_3$ | $P_3$ | $p_3$ |
| ... | ... | ... | ... | ... |

To get the pressure due to the alcohol alone we must subtract from the numbers in the third column the corresponding pressures due to the air, entered in the fourth column. To get them, let us find $P_3$. If $P_0$ be the pressure of the air, if it were cooled to 0°C, and if $a$=·00366, the coefficient of expansion of air, then

$$P_3 = P_0 (1 + at_3)$$
$$P_1 = P_0 (1 + at_1),$$
$$\therefore P_3 = \frac{1 + at_3}{1 + at_1} \times P_1.$$

Plot a curve, taking the temperatures as abscissae, and the corresponding vapour-pressures of alcohol as ordinates.

Determine as above the vapour-pressure of Turpentine.

**45. To find by Regnault's Hygrometer (*a*) the dew point; (*b*) the pressure of aqueous vapour in the air; (*c*) the relative humidity of the air.**

[Take a boiling tube $A$ from 2 to 3 cm. in diameter and silver the bottom of it as described in Appendix B. 8. Through a cork fitting this tube pass a thermometer $T$ and two elbow-tubes $B$ and $C$, one of which reaches almost to the bottom of the boiling tube.]

*Apparatus* (Fig. 14). Aspirator.

*Experiment.* Pour some ether into the Hygrometer so as to cover the bulb of the thermometer when the cork is replaced. Attach the elbow-tube $B$ to an aspirator. As the water flows out of the latter, air, entering the tube $C$, bubbles through the ether, which therefore evaporates quickly. The external air

ing tube is in

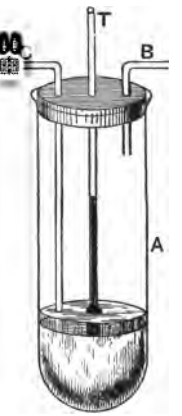


Fig. 14.

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**46. Determination of the constant of a wet and dry bulb Hygrometer.**

*Apparatus.* Two thermometers: Vessel of water.

*Experiment.* Hang the two thermometers about 10 cm. apart from one another. Cover the bulb of one with fine muslin, to which is attached a piece of loose cotton thread (such as is used for the wick of an oil-lamp) long enough to dip into the small vessel of water[48]. The muslin and cotton are to begin with thoroughly wetted with distilled water, then the water from the cistern rises up the thread by capillary action, and the bulb is thus kept constantly wet.

The two thermometers and small vessel of water ought to be fixed to a wooden support and hung on the wall of the laboratory in a permanent position.

In consequence of the continual evaporation the temperature of the wet-bulb thermometer is always lower than that of the dry-bulb thermometer. It is proved in books on physics that

if $t$ is the temperature of the dry-bulb thermometer,
$t'$ the temperature of the wet-bulb thermometer,
$F'$ the maximum pressure of water vapour at temperature $t'$,
$f$ the pressure of the water vapour in the air,
and $H$ the barometric height,

then $f = F' - AH\,(t - t')$, where $A$ is the '*constant*' of this instrument.

To determine $A$, read $t, t'$, and the barometric height $H$. Look in tables for $F'$, and find $f$ by Regnault's Hygrometer (Experiment 45). Substitute their values in the above equation, and so determine $A$.

Having once determined $A$ for the particular position in which the instrument is always in future to be used, we can evidently determine $f$, the vapour pressure in the air, by reading the dry and wet-bulb thermometers and the barometric height, and finding the value of $F'$ from the tables.

[48] The muslin and lamp cotton should, before use, be boiled in water containing a little washing soda to get rid of grease.

***47. Determination of the mass of 1 litre of Laboratory air by reading the barometer, thermometer and hygrometer.**

*Apparatus.* Thermometer: Hygrometer.

*Experiment.* The mass of a litre of laboratory air equals the mass of the dry air added to the mass of the vapour contained in it at the existing temperature and pressure.

Read the temperature $t$ of the air, and the barometric height $H$, and determine by Regnault's Hygrometer the pressure, $f$, of the vapour in the air.

i. *To determine the mass of a litre of dry air.*

The mass of a given volume of air varies directly as its pressure and inversely as its temperature above $-273°C$. The mass of one litre of dry air at $0°C$ and under 760 mm. pressure is 1·293 grs., therefore its mass at its present temperature, $t$, and under its present pressure, $H-f$, is

$$m_1 = \frac{H-f}{760} \times \frac{273}{273+t} \times 1{\cdot}293 \text{ grs.} \qquad \text{(i)}$$

ii. *To determine the mass of a litre of vapour.*

The mass of a given volume of vapour is $\frac{5}{8}$ths that of an equal volume of dry air at the same temperature and pressure as the vapour. The vapour is at the temperature, $t$, and under a pressure, $f$.

The mass of one litre of dry air under these conditions is

$$\frac{f}{760} \times \frac{273}{273+t} \times 1{\cdot}293 \text{ grs.},$$

therefore the mass of one litre of the vapour is

$$m_2 = \tfrac{5}{8} \times \frac{f}{760} \times \frac{273}{273+t} \times 1{\cdot}293 \text{ grs.} \qquad \text{(ii)}$$

Adding (i) and (ii) together, we get for the mass of a litre of the laboratory air,

$$M = m_1 + m_2 = \frac{H-\frac{3}{8}f}{760} \times \frac{273}{273+t} \times 1{\cdot}293 \text{ grs.}$$

Substituting for $H, f, t$ we get $M$, the mass required.

## E. RADIATION.

**48. To investigate the truth of Newton's law of cooling.**

*Apparatus.* Tin vessel about 200 c.c. capacity: Large Beaker: Thermometer: Bunsen Burner: Curve-paper.

*Experiment.* Newton stated that when a heated body cooled in an enclosure of constant temperature, its velocity of cooling is proportional to its excess of temperature over that of the enclosure. Let us take a thermometer as the body to be heated and allowed to cool. In order to keep the temperature of the enclosure constant take the tin vessel and float it in a large beaker of water, so that the water level is about 2 cm. from the top of the vessel on the outside—sand or shot may be used as ballast. Take a piece of wood to be used as a cover, bore a hole in the middle of it, and fit a cork, through which the thermometer passes, to the hole. Take out the thermometer and heat it carefully to about 70° or 80° in the hot air rising from a flame. Replace it in the cork and arrange the cover so that the thermometer dips into the empty tin vessel. Note the temperature every half-minute as it cools down to the temperature of the room, and enter your results as follows:—

Temperature of the enclosure $t$...

| Observed temperature. | Excess of temperature. | Average excess every half-minute. | Fall in degrees every half-minute. | Fall. / Average excess. |
|---|---|---|---|---|
| $t_1$ | $\theta_1$ | $\frac{\theta_1+\theta_2}{2}$ | $t_1-t_2$ | ... |
| $t_2$ | $\theta_2$ | | | |
| $t_3$ | $\theta_3$ | $\frac{\theta_2+\theta_3}{2}$ | $t_2-t_3$ | ... |
| ... | ... | ... | ... | ... |

The numbers in the second column are obtained by subtracting the temperature $t$ of the water in the beaker from each of those in the first column.

The numbers in the third column are the average of successive pairs of numbers in the second column.

The numbers in the fourth column are the differences between successive pairs in the first column.

The numbers in the fifth column are the quotients of corresponding numbers in the third and fourth columns.

If Newton's Law were true this last series would be constant. It will be found, however, that as the temperature decreases the numbers decrease somewhat, which shows that Newton's Law is not quite exact, and that the fall diminishes quicker than the excess, i. e. they are not quite proportional to each other.

Plot your results in a curve, taking the fall in degrees every half-minute as abscissae, and the corresponding average excesses as ordinates.

***49. To plot the curve of cooling for a calorimeter and to determine how much heat is given off by it in unit time at a given temperature.**

*Apparatus.* Calorimeter: Thermometer: Bunsen Burner: Curve-paper.

*Experiment.* Counterpoise the calorimeter. Boil some water in a beaker, and pour some of it into the calorimeter so as to very nearly fill it. Support a thermometer so that its bulb is immersed under the surface of the hot water, and observe the temperatures every half-minute as the calorimeter cools to the temperature of the room. At the end weigh the calorimeter and find the mass, $m$, of water introduced.

Enter your results in a tabular form, and plot them on a curve, taking the times as abscissae and the corresponding temperatures as ordinates. This curve is called the *cooling curve* for the calorimeter. It is independent of the nature of the liquid contained in it. (Experiment 35.)

To determine the quantity of heat given off by the calorimeter in unit time at a certain temperature, say at 50°. Through the point on the temperature axis corresponding to 50° draw a horizontal straight line cutting the curve at the point $P$. Through $P$ draw a tangent to the curve and continue it to cut both axes. The tangent of the angle this tangent makes with the time-axis evidently gives us the rate of cooling at 50°. Let

the tangent cut the temperature axis at a point corresponding to a temperature $T$, and the time axis at a point corresponding to $N$ half-minutes. Then at 50° it would cool $T^\circ$ in $N$ half-minutes, therefore $\frac{T^\circ}{N}$ in one half-minute. The quantity of heat given off depends on the mass and nature of the liquid in the calorimeter. If $m$ is the mass of water, and $\mu$ the water value of the calorimeter, the quantity of heat given off at 50° during the half-minute is evidently $(m+\mu)\frac{T}{N}$.

If we had filled the calorimeter with a mass $m$ of another liquid we should have to substitute $ms$ in the above for $m$, where $s$ is the specific heat of the liquid.

Determine as above the quantity of heat given off by (1) water, and (2) mercury at 40° from the same calorimeter.

---

The *emissive power* of a substance is that quantity of heat emitted normally from unit area in unit time when its excess of temperature is 1° above that of the enclosure.

**50. To compare the emissive powers of two substances, e. g. Lampblack and Tinfoil.**

*Apparatus.* Two vessels of as nearly the same size and shape as possible[49]: Thermometer: Beaker: Bunsen Burner: Curve-paper.

*Experiment.* Cover the outside of one vessel with lampblack by holding it in an ordinary gas flame. Fill it nearly with boiling water and arrange the thermometer with its bulb immersed in the water, and note the time it takes to cool every 5°, till the temperature has fallen to about 40°. Now cover the outside of the other vessel to the same height with strips of tinfoil. Fill it with boiling water to the same height as in the first case and note the time it takes to cool every 5° through the same range of temperatures.

[49] Small conical flasks of about 80 c.c. do very well.

Arrange your results in a tabular form as follows :--

| Temperatures. | Time of cooling. | | Ratio of emissive powers $\frac{n'}{n}$ |
|---|---|---|---|
| | Tinfoil. | Lampblack. | |
| 90°—85° | $n_1$ | $n'_1$ | ... |
| 85°—80° | $n_2$ | $n'_2$ | ... |
| ... | ... | ... | ... |

Mean .....

While the temperature decreases, say from 90° to 85°, the quantity of heat given off per minute from the tinfoil surface, if $M$ is the mass of water, is

$$\frac{5(M+\mu)}{n_1},$$

and from the lampblack surface of the same area it is

$$\frac{5(M+\mu)}{n'_1},$$

so that the ratio of the emissive power of tinfoil to that of lampblack is

$$\frac{n'_1}{n_1}.$$

Calculate the ratios for the successive ranges of temperature and enter them in the fourth column.

Compare the emissive powers of varnish, white lead, paper.

## APPENDIX A.

| (1) Volume of unit mass and density of water at different temperatures. | | | (2) Volume of 1 c.c. at 0° and density of mercury at different temperatures. | |
|---|---|---|---|---|
| $t°$ C. | Volume of unit mass. | Density. | Volume of 1 c.c. at 0°. | Density. |
| 0 | 1·0001 | 0·99988 | 1·0000 | 13·596 |
| 4 | 1·0000 | 1·00000 | 1·0007 | 13·586 |
| 10 | 1·0003 | ·99976 | 1·0018 | 13·572 |
| 15 | 1·0008 | ·99917 | 1·0027 | 13·559 |
| 20 | 1·0017 | ·99827 | 1·0036 | 13·547 |
| 25 | 1·0029 | ·99713 | 1·0045 | 13·535 |
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| 50 | 1·0120 | ·98821 | 1·0090 | 13·474 |
| 55 | 1·0144 | ·98580 | 1·0099 | 13·462 |
| 60 | 1·0169 | ·98339 | 1·0108 | 13·450 |
| 65 | 1·0197 | ·98067 | 1·0117 | 13·438 |
| 70 | 1·0226 | ·97795 | 1·0127 | 13·426 |
| 75 | 1·0257 | ·97495 | 1·0136 | 13·414 |
| 80 | 1·0289 | ·97195 | 1·0145 | 13·401 |
| 85 | 1·0322 | ·96876 | 1·0154 | 13·389 |
| 90 | 1·0357 | ·96557 | 1·0163 | 13·377 |
| 95 | 1·0394 | ·96212 | 1·0172 | 13·365 |
| 100 | 1·0432 | ·95866 | 1·0182 | 13·353 |

(3) *Densities.*

| | |
|---|---|
| Lead | 11·4 |
| Iron | 7·76 |
| Copper | 8·95 |
| Glycerine | 1·26 |

(4) *Coefficients of Expansion (absolute).*

| | |
|---|---|
| Glass (cub.) | ?.000026 |
| Zinc (lin.) | ·000029 |
| Copper (lin.) | ·000016 |
| Brass (lin.) | ·000019 |
| Iron (lin.) | ·000012 |
| Amyl Alcohol (cub.) | ·00109 |
| Glycerine (cub.) | ·000526 |
| Turpentine (cub.) | ·00105 |
| Air (cub.) | ·00366 |

(5) *Melting-points.*

| | |
|---|---|
| Paraffin-wax | 45° |
| Beeswax | 62° |
| Stearic Acid | 69·9° |
| Benzoic Acid | 121° |
| Tin | 235° |
| Lead | 335° |

(6) *Boiling-points.*

| | |
|---|---|
| Methyl Alcohol | 66·3° |
| Benzol | 80·4° |
| Turpentine | 156° |
| Ether | 35·5° |
| Carbon Bisulphide | 48° |

*of fusion.*

. . . . 79·25
. . . . 97·22

*isation under a*
*m. of mercury.*

. . . . 536
. . . . 264
. . . . 69

*m. of Mercury.*

| | | t° | |
|---|---|---|---|
| | 21 | 100·1 | 762·73 |
| | 65 | 100·2 | 765·46 |
| | 50 | 100·3 | 768·20 |
| | 16 | 100·4 | 771·95 |
| | 83 | 100·5 | 773·71 |
| | 50 | 100·6 | 776·48 |
| | 18 | 100·7 | 779·26 |
| | 87 | 100·8 | 782·04 |
| | 57 | 100·9 | 784·83 |
| | 28 | 101 | 787·59 |
| | 00 | 105 | 906·41 |

centimetres.
q. centimetres.
cub. centimetres.
am.
23 grams.

the Centigrade

eighs nearly as
ub. cm. of water

## APPENDIX B.

**1. To graduate and calibrate a glass bulb-tube and to fill it with a liquid.**

(*a*) To graduate it cover the whole of the stem with a uniform thin layer of paraffin-wax. Fix it along a metre scale, and with a fine needle make a scratch at intervals of ·5 cm., and scratch the numbers of every fifth division [50]. With cotton wool at the end of a stick brush some solution of Hydrofluoric Acid over the tube and leave it for ten minutes. The acid will etch the glass where it is exposed. Finally melt off the wax and dissolve any that remains with ether.

(*b*) To calibrate it weigh the empty bulb-tube. Place it with its open end under some clean dry mercury, and by driving out the air by heat fill the tube partly with the mercury, and allow it to cool to the temperature of the room. Suppose the mercury reaches to the $n^{\text{th}}$ division on the stem. Weigh again and determine the mass, $M$, of the mercury it contains. The volume of the bulb and the $n$ divisions is $\frac{M}{\sigma}$ c.c., where $\sigma$ is the density of mercury at the temperature of the room. Therefore if $B$ is the volume of the bulb [up to the point where the divisions begin] and $v$ the volume of one division,

$$B + nv = \frac{M}{\sigma}.$$

Now introduce as before some more mercury, say up to the $m^{\text{th}}$ division, and find the total mass, $M'$, of the mercury contained in the tube. Now we have

$$B + mv = \frac{M'}{\sigma}.$$

From the above two equations we can find the volume $B$ of the bulb and $v$ the volume of each division of the stem.

(*c*) A convenient method of filling the bulb-tube is to support it vertically. Connect the top of the stem by a short piece of

[50] We suppose the tube to be of uniform bore.

india-rubber tubing with a large funnel resting in a ring of a retort-stand. Fill the funnel with liquid and heat the bulb carefully with a burner. By this means the air is expelled and the liquid can be made to fill the tube.

**2. To graduate and calibrate a glass tube.** Take a narrow strip of gummed paper as long as the tube to be graduated and mark off along it divisions ·5 cm. apart. Stick the paper along the tube. Take a short piece of the same glass-tubing and smooth its ends flat on sand paper moistened with turpentine. Measure its length, $l$. Counterpoise a crucible. Place the tube horizontally under the surface of some clean mercury so that it may be filled with it. Close the two ends by the fingers and take the tube out of the mercury and transfer the mercury it contains to the crucible. Weigh and find the mass, $m$, of the mercury. Read the temperature, $t$, of the room. Find from the tables the density $\sigma$ of mercury at this temperature. Then $\frac{m}{\sigma}$ is volume of a length $l$ cm. of the tube, therefore the volume of each of the divisions on the graduated tube is $\frac{m}{2l\sigma}$ cubic cm.

**3. To clean and dry glass vessels.** Rinse them out successively with (1) Nitric Acid, (2) Distilled Water, (3) Caustic Potash, (4) Distilled Water, (5) Alcohol, (6) Ether. To dry them take a piece of hard glass tube about 20 cm. long and 1 cm. in diameter. Draw out one end so that it may be sufficiently small to insert in the vessel. Bend the tube at right angles about 5 cm. from this end. Fix the tube in a clamp with its bent end vertical, and gently heat the horizontal portion with a large Bunsen. By means of india-rubber tubing attached to the larger end of the glass tube and to a pair of bellows, cause a gentle current of hot air to pass into the vessel, which must be placed resting mouth downwards on the upright portion of the glass tube. A very useful piece of apparatus for this and other purposes is the hand-bellows sold by chemists to be used with a throat spray.

**4. To clean mercury.** A piece of clean writing paper is folded twice at right angles and then opened out in the form of a cone; it is then fitted into a glass funnel. A few holes are made with a fine needle near the apex of the paper cone, so that when mercury is poured in the liquid escapes through these in fine streams. Mercury filtered in this way is quite free from dust. Another method is to pour the mercury into a handkerchief and press it through the interstices of the linen.

**5. To make a cork water-tight.** Soak the cork thoroughly in water and then place it in oil, and heat to about 120°.

**6. Black Varnish.** A good dead black varnish for radiation experiments may be made by putting 2 grams of lamp-black (or 'vegetable black') into a mortar, weighing into the vessel 8 grams of gold size, grinding the whole together into a smooth paste and adding 10 grams of turpentine. The whole must be stirred thoroughly together just before use, and laid on evenly with a soft brush. It adheres better if the surface is slightly warmed previously, and heated more strongly after the coating is applied.

**7. Silvering Solution.** Make two solutions as follows:—

(*a*) Two grams of silver nitrate are dissolved in 16 c.c. of distilled water; to this ammonia is added until the precipitate first thrown down is almost entirely re-dissolved. The solution is filtered and diluted to 200 c.c.

(*b*) Two grams of silver nitrate are dissolved in a little distilled water and this is poured into a litre of rapidly boiling distilled water. 1·66 gram of Rochelle salt (Potassium Sodium Tartrate) is added, and the mixture boiled for a short time till the precipitate contained in it becomes grey. This is then filtered while hot. The boiling tube to be silvered has to be thoroughly cleaned inside with (1) Nitric Acid, (2) Distilled Water, (3) Caustic Potash, (4) Distilled Water, (5) Alcohol, (6) Distilled Water. Equal volumes of the above solutions are mixed together and poured into the boiling tube up to the level required to be silvered. In about an hour the silvering will be

complete. Pour off the exhausted liquid, rinse out with distilled water. Throughout the whole operation the most scrupulous cleanliness is absolutely essential.

**8. Curves and Curve-paper.** Paper ruled in centimetres and millimetres can be obtained from Messrs. Williams and Norgate and Waterlow and Sons. The observed points of the curve may be marked with small dots made with a hard sharp pencil, and these may be marked by small crosses. In drawing the curve the successive points may be first joined by thin straight lines, and a smooth curve then drawn through them in a freehand manner [see Note 5, and also *Practical Work in General Physics*, Appendix B. 2].

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